



**AFRL-RQ-WP-TM-2016-0086**

# **BUILDING 65 HYDRAULIC SYSTEMS HANDBOOK: COMPONENTS, SYSTEMS, AND APPLICATIONS**

**James Eichenlaub**

**Booz Allen Hamilton**

**APRIL 2016**

**Interim Report**

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<b>14. ABSTRACT</b> Hydraulics is the preferred method of power transmission for most of the types of structural tests performed in the Aerospace Structural Test Facility of the Air Force Research Laboratory in Building 65, WPAFB. This handbook documents the Building 65 hydraulic system, which includes reservoirs, pumps, and distribution lines. It also contains information on equipment used to create unique load test circuits for individual projects. It familiarizes users with the resources available and the hydraulic design philosophy used in this facility. Systems range in complexity from simple manually operated hand pumps to sophisticated servo-hydraulic closed loop load control systems.								
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## 1. Introduction

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The purpose of this document is to provide a one-stop shop for information on the Building 65 hydraulic systems. You will find information on the permanent facility systems such as reservoirs, pumps, and distribution lines. You will also find information about the equipment used to create unique load test circuits for individual projects. This document will familiarize the reader with the resources available and the design philosophy used in this facility for over twenty years. Systems range in complexity from simple manually operated hand pumps to sophisticated servo-hydraulic closed loop load control systems. This document should be a living document to be updated as necessary.

This document is **NOT** intended to teach the fundamentals of hydraulics. There are many tutorial books and classes available on this subject. It is recommended that the untrained reader receive some formal training to get the most out of this manual.

### How to Use This Handbook

This document can be used by engineers of the Building 65 Facility to help design hydraulic systems in-house for testing. In contrast, it could be used by outside organizations to determine the capabilities of the facility. Technicians can consult this document for information to help perform maintenance on facility systems or test equipment. In addition, new employees can read this document to get a jump start on learning the hydraulic systems' capabilities and resources available here in this facility.

Most of the information in this document revolves around the facility schematics found in **Appendix A**. To get the most out of this document, start by becoming familiar with the symbols in the section **Some Basics** if you are not already familiar with them. Then study the schematics in **Appendix A** to get the general relation of all the facility systems and test site equipment.

Next, for someone new to the facility, it is recommended that they read the entire document to gain an understanding of individual hydraulic components, facility equipment operation, and design philosophy used to build test systems to conduct load tests in this facility. The reader may want to refer back to the schematics in **Appendix A** at any time to see how the particular section being read fits into the big picture.

The experienced user can reference any particular section of this document to find pertinent information on the topic of interest.

If any of the schematics are not readable, remember "C" size prints are available in the facility vault for use.

### What's Inside

**Section 2** summarizes some basic hydraulic information to refresh the reader's knowledge of common hydraulic symbols and equations that they should already be familiar with. Also, the functions of all the valves and other components used in the circuits in this document are briefly explained.

**Section 3** describes the hydraulic supply system including oil reservoirs, boost pumps, high pressure pumps, and the distribution lines that run throughout the facility.

**Section 4** describes the multiple functions of Service Manifolds. Service Manifolds are an essential part of a servo-hydraulic load system. They interface each test site to the main hydraulic supply system. They are controlled by the test operator and load control system to maintain test article safety at all times.

**Section 5** introduces the Servo Valve Manifolds and their functions. Servo Valve Manifolds distribute the output flow from Service Manifolds to individual actuators used to apply loads to a test article. They also perform other necessary functions.

**Section 6** provides information on the use and operation of the Controlled Abort Manifold. Controlled Abort Manifolds are necessary when a test article must be unloaded in a

precise and coordinated fashion during an emergency abort. They also add the capability to limit the maximum load that can be applied to a test article. It is not always necessary to use Controlled Abort Manifolds.

**Section 7** is devoted to the operation of servo valves and why they are required for closed loop load control.

**Section 8** explains the importance of the Emergency Dump Buttons and how they should be used. Emergency Dump Buttons can shut down the entire hydraulic supply system, or shut down a particular test site, or they can shut down an individual piece of equipment. Knowing which button to push in a given emergency situation is critical.

**Section 9** explains the importance of oil cleanliness and how the facility Oil Care Program is maintained by the PM/PMI logistics team.

**Section 10** summarizes information on other essential hydraulic equipment which may not be used as often as the equipment described in the previous sections, but may be better suited for a unique load test or equipment checkout. Sometimes a simple setup is better and quicker than a full blown servo-hydraulic system and will yield the same results.

**Section 11** provides schematics of circuits used for tests conducted in the past. Many times a previously used circuit can be re-used as-is or with slight modifications.

**APPENDIX A** contains a set of schematics for the facility Hydraulic Supply System. They show the entire hydraulic distribution system starting with the oil reservoir and progresses through the system to Service Manifolds, Servo Valve Manifolds, and then on to actuators which are used to load test articles. Information on other components in the system is described in detail in other sections of this document.

**APPENDIX B** contains an enlarged schematic for the Controlled Abort Manifold. The complexity is too much to put on the standard page.

**APPENDIX C** illustrates the operation of the Service Manifold and a single Controlled Abort Manifold channel including startup, abort scenarios, and shut down. These illustrations are color coded to show pressures and also have arrows to show flow paths and directions.

## 2. Some Basics

---

Fluid power (hydraulics) is the preferred method of power transmission for most of the types of structural testing applications performed here in Building 65. Hydraulic systems are popular because they can transmit a large amount of power long distances through small tubes or flexible hoses to out-of-the-way places and allow a fine degree of control, including reversibility and infinite speed and load variation. The systems in this facility use petroleum oil because it prolongs the life of components, while reducing the size of the system and increasing its efficiency by permitting operation at higher pressures.

This section will summarize some basic information about hydraulics including fundamental equations, common components and their symbols used in the circuits in this manual. It is assumed that the reader has had some type of training on the fundamentals of hydraulics.

### COMMON EQUATIONS

The following are some equations commonly used in system designs:

Force

$$\text{Force (lb.)} = \text{Pressure (psi)} \times \text{Area (in}^2\text{)}$$

Flow

$$\text{Flow (in}^3\text{/sec)} = \text{Velocity (in/sec)} \times \text{Area (in}^2\text{)}$$

$$1 \text{ Gallon} = 231 \text{ in}^3$$

Horsepower

$$\text{HP} = \text{Flow (gpm)} \times \text{Pressure (psi)} / 1,714$$

Max Hose Velocity

$$V \text{ (ft/sec)} = .4081 \times \text{Flow (gpm)} / D^2(\text{in})$$

$$D = \text{Inside Diameter}$$

## COMMON COMPONENTS

The following paragraphs describe the components used in the circuits found in this document. You will also find the symbol used to represent them.



Hand Valve

Used to limit flow from fully open to fully closed by manually turning a handle.



Check Valve

A check valve passes flow in one direction and blocks flow in the other direction.



Pressure Gauge

A mechanical instrument used to measure pressure.



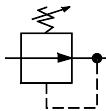
Pressure Transducer

A sensor which outputs an electrical signal proportional to pressure.



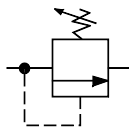
Filter

A device used to remove contaminants from an oil stream.



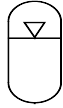
Pressure Regulator

A valve that automatically reduces the pressure on the inlet to a predetermined pressure on the output. The output pressure setting is manually adjusted by changing the compression on a spring.



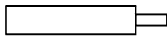
Pressure Relief

A valve that opens when a predetermined pressure is exceeded on the inlet side. The opening pressure setting is manually adjusted by changing the compression on a spring.



Accumulator

A pressure vessel which operates as a fluid source device or shock absorber. It is used to store fluid under pressure or to absorb excessive pressure increases.



Cylinder

A mechanical actuator used to give a unidirectional force through a unidirectional stroke.



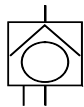
Adjustable Orifice

Used to control the rate of fluid flow. The flow rate is manually adjusted by turning a knob to change the opening size.



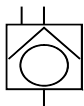
Pressure Compensated  
Adjustable Orifice

Used for a more precise control of rate of fluid flow. Automatically adjusts to maintain a constant flow rate under changing pressure conditions.



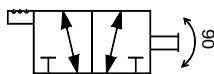
Pilot to Close Check Valve

Works like a standard check valve except that it can be closed remotely to prevent free flow by applying oil pressure to a third port (pilot port).



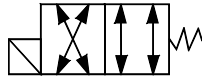
Pilot to Open Check Valve

Works like a standard check valve except that it can be opened remotely to allow reverse flow by applying oil pressure to a third port (pilot port).



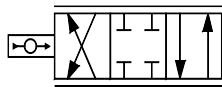
3 Way Manual Valve

A manually actuated spool valve that allows a source to be routed to one of two possible paths.



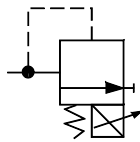
4 Way Solenoid Valve

A solenoid actuated spool valve that allows reversal of fluid flow.



Servo Valve

A valve used to direct fluid to an actuator in a closed loop control system. The flow rate is proportional to the amplitude of an electrical input signal. The flow direction is determined by the polarity of the electrical input signal.



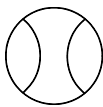
Proportional Relief Valve

Works like a standard relief valve except that its setting can be set remotely. The relief setting is proportional to an electrical input signal.



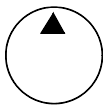
Reservoir

A tank that stores the excess hydraulic fluid. It helps separate air from the fluid and can separate dirt from the fluid



Flow Meter

A mechanical or electrical device used to measure fluid flow.



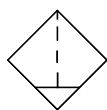
Pump

Supplies fluid to the components in the system. Pressure in the system develops in reaction to the load. A pump rated for 3,000 psi is capable of maintaining flow against a load of 3,000 psi.



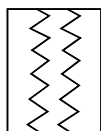
Motor

Electrical motors are used to turn pumps.



Strainers

A device used to separate larger particles from a liquid.



Heat Exchanger

A device used to transfer heat from one fluid to another without direct contact of the fluids.

### 3. Pumps and Distribution System

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#### System Description

A schematic of the pumps and distribution system is shown on page 1 of **Appendix A**. The pumps, reservoirs, and associated equipment which make up the Hydraulic Supply System (HSS) for the Building 65 complex are located in room 109N and in the lower level below room 109N. The HSS is actually two identical and independent systems which should be operated individually. Each system can deliver 350 GPM at 3,200 PSI each. The HSS can be accessed at test sites throughout the main test floor, the FIRST Lab, and the Acoustic Facility via lines running in trenches below the floor.

Each system has a 2,000 gallon oil reservoir, 2 boost pumps, a filter, a heat exchanger, and a set of two high pressure pumps. The reservoirs for the two systems are always connected to each other via two 2" communication lines to allow oil to be used from both tanks and still maintain equal levels. When a system is running, oil flows from the reservoir by gravity to a boost pump which increases the oil pressure from atmospheric pressure to about 35 PSI. The oil then flows through a filter, a heat exchanger and then into one or more high pressure pumps which increase the oil pressure to 3,200 PSI. The oil coming out of the high pressure pumps then goes into the main distribution lines.

An advantage of having two independent systems is that maintenance can be performed on one system while still providing hydraulic power to tests with the other system.

#### Oil Reservoirs

The oil in the reservoirs is Mobil DTE 24. The oil level should be maintained at about 1,200 gallons or about 36 inches on the level gauge for each reservoir.

#### Boost Pump Skids

See the schematic on page 16 and **Appendix A** for this discussion. There are two Boost pump Skids located in the lower level of Room 109N. There is one Boost Pump Skid for each system. Oil enters the Boost Pump Skid from

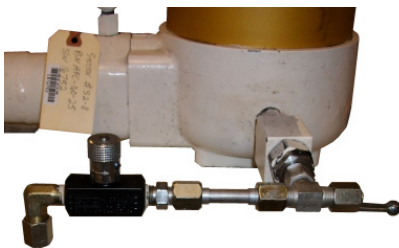


the reservoir at atmospheric pressure and goes into the suction line of four pumps. The four pumps are in groups of two. Each pair is driven by a single motor to produce 200 GPM constant flow rate. The oil then goes through a filter normally with a 10 micron cartridge. The pumps are capable of producing 3,000 PSI, but other components of the Boost Skid have a much lower pressure rating. Therefore a relief valve set to 35 PSI is connected from the heat exchanger outlet directly back to the reservoir. In addition there is a redundant relief valve set to 60 PSI connected to the filter outlet directly back to the reservoir. After the oil is filtered, it goes through a heat exchanger to maintain an acceptable temperature. The temperature of the oil at the heat exchanger outlet should be around 110 degrees F at steady state conditions. The oil then passes through a flow meter and then goes to the high pressure pumps if needed or it may go back to the reservoir.

Only the flow needed at a test site goes through the high pressure pumps. The rest of the oil that goes through the Boost Pump (the difference between 200 GPM and test site needs) goes back to the reservoir. So if there is little demand for oil at test sites, the oil is just being filtered over and over without doing any work. This keeps the oil clean all the time. For example, if one boost pump pair is running, it is pumping 200 GPM constantly. If a total of 20 GPM is needed at test sites, then 180 GPM of the output of the boost pumps is just circulating through the filters and heat exchangers. If there is 1,200 gallons of oil in the reservoir, then the oil gets cleaned about every 6 minutes.

### Oil Sampling Ports

Each Boost Pump Skid has two oil sampling ports used for gathering oil samples periodically. See the section on the **Oil Care Program** for more information.



### Monitoring System



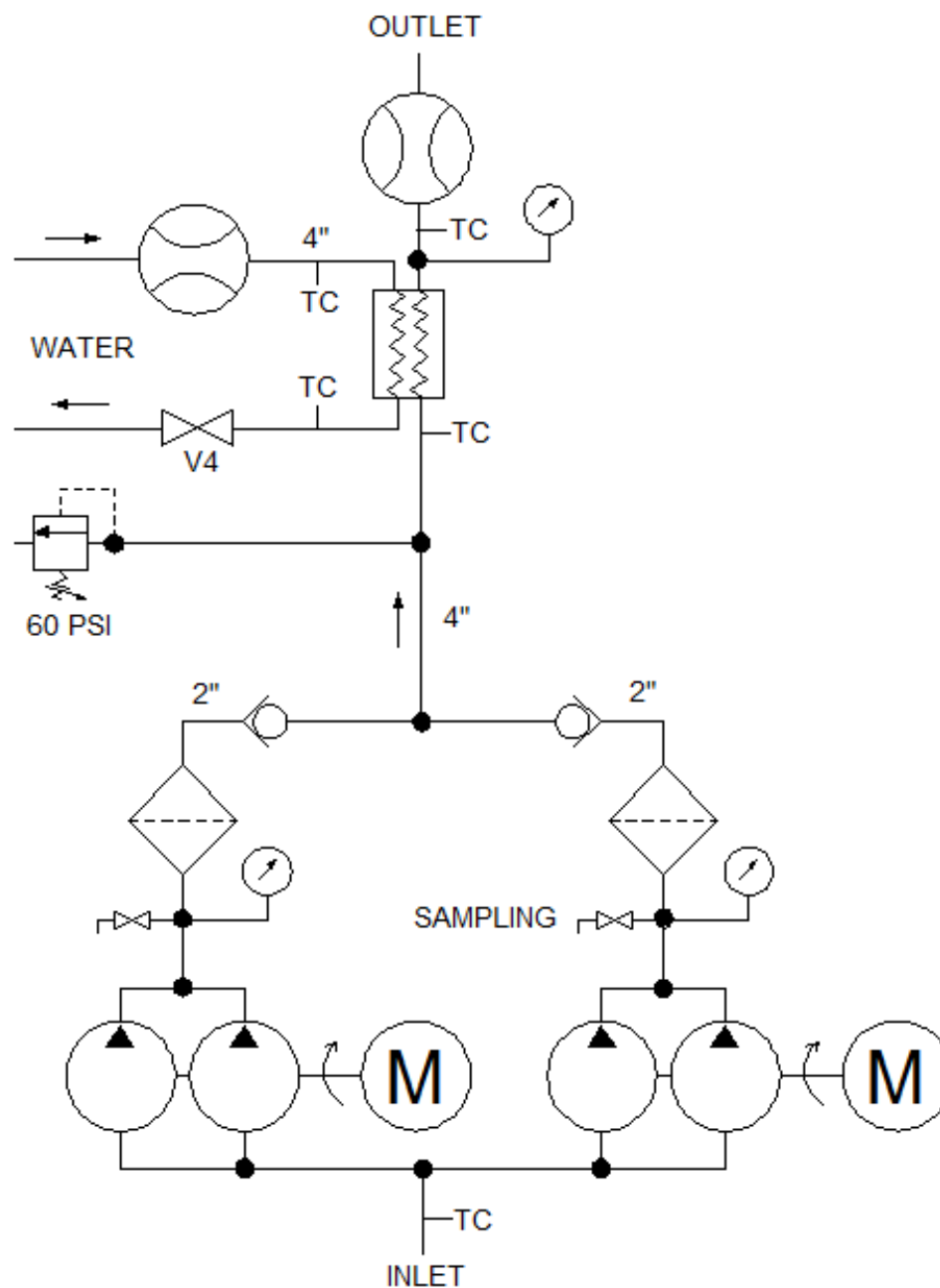
Each Boost Pump Skid has measuring instruments to monitor flow, pressure, temperatures of both oil and cooling water. These measurements are constantly monitored by a computer system to protect the hydraulic system and personnel. If any of these measurements exceed predefined limits, the Monitoring System will take appropriate actions to protect the hydraulic system. The Monitoring System is capable of shutting down the hydraulic system and/or notifying personnel in the facility or at any remote location. The monitoring system is linked to the Test Area Network and can be accessed throughout the facility.

### Changing the Filters

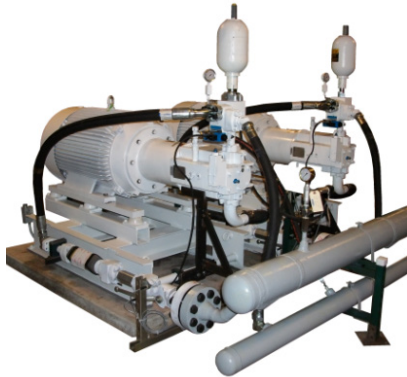
Each filter housing has a differential pressure gauge to indicate the condition of the filter cartridge. When the differential pressure reaches 15 PSI, the cartridge is due to be changed. Changing the filters is part of the facility Preventive Maintenance/Preventive Maintenance Inspection program.

### Changing the Hoses

The suction hoses on the Boost Skids should be changed at least every 5 years. Changing the hoses is part of the facility PM/PMI program.

**Boost Pump Skid  
Schematic**

### High Pressure Pumps



See the schematic on page 19 for this discussion. There are four high pressure pumps located in Room 109N. Each hydraulic system has a manifold that can accommodate four pumps. At the current time there are two pumps connected to the manifold for each system. There are also two capped flanges on each system where additional pumps could be added in the future if needed.

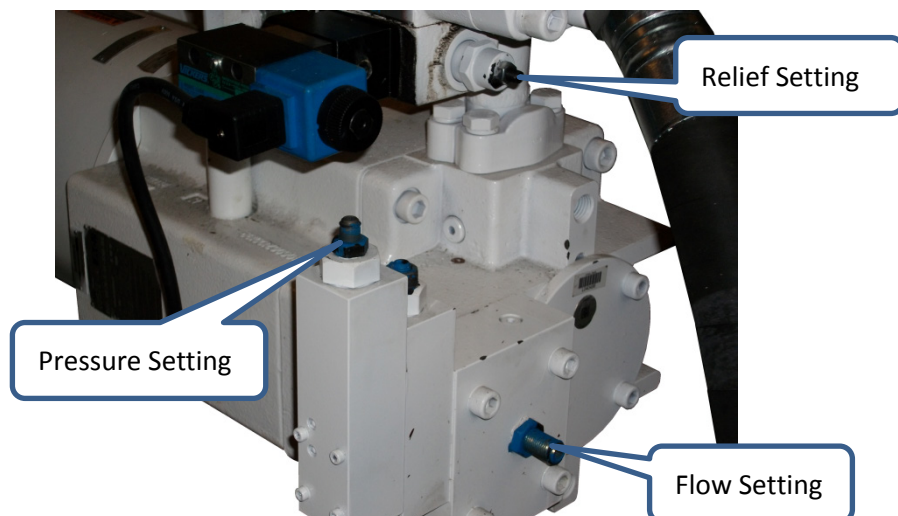
Oil enters the high pressure pump manifold from the boost pumps at about 35 PSI and goes into the suction line of each high pressure pump. When the pump is energized, the relief valve vent is closed off and pressure builds to the preset pressure adjusted on the compensator. In addition, the manifold bleed valve (shown in Appendix A page 1) closes. The accumulator charges to the system pressure and reduces ripples in the output flow.

### Adjusting the Max Flow Rate

The maximum pump output flow can be set using the adjustment screw shown in the figure below. Turning the adjusting screw clockwise will increase the output flow rate.

### Adjusting the Output Pressure

The pump output pressure can be set using the adjustment screw shown in the figure below. Turning the adjusting screw clockwise will increase the output pressure. The relief setting may have to be adjusted in order to reach the desired setting.



### Adjusting the Relief Setting

The maximum pump output pressure can be limited by setting the adjustment screw shown in the figure above. Turning the adjusting screw clockwise will increase the output pressure. If the relief valve is constantly relieving, then the pressure output adjustment needs to be changed to lower the output pressure.

### Changing the Hoses

All the hoses on the high pressure pumps should be changed at least every 5 years. Changing the hoses is part of the facility PM/PMI program.

### Oil Sampling Ports

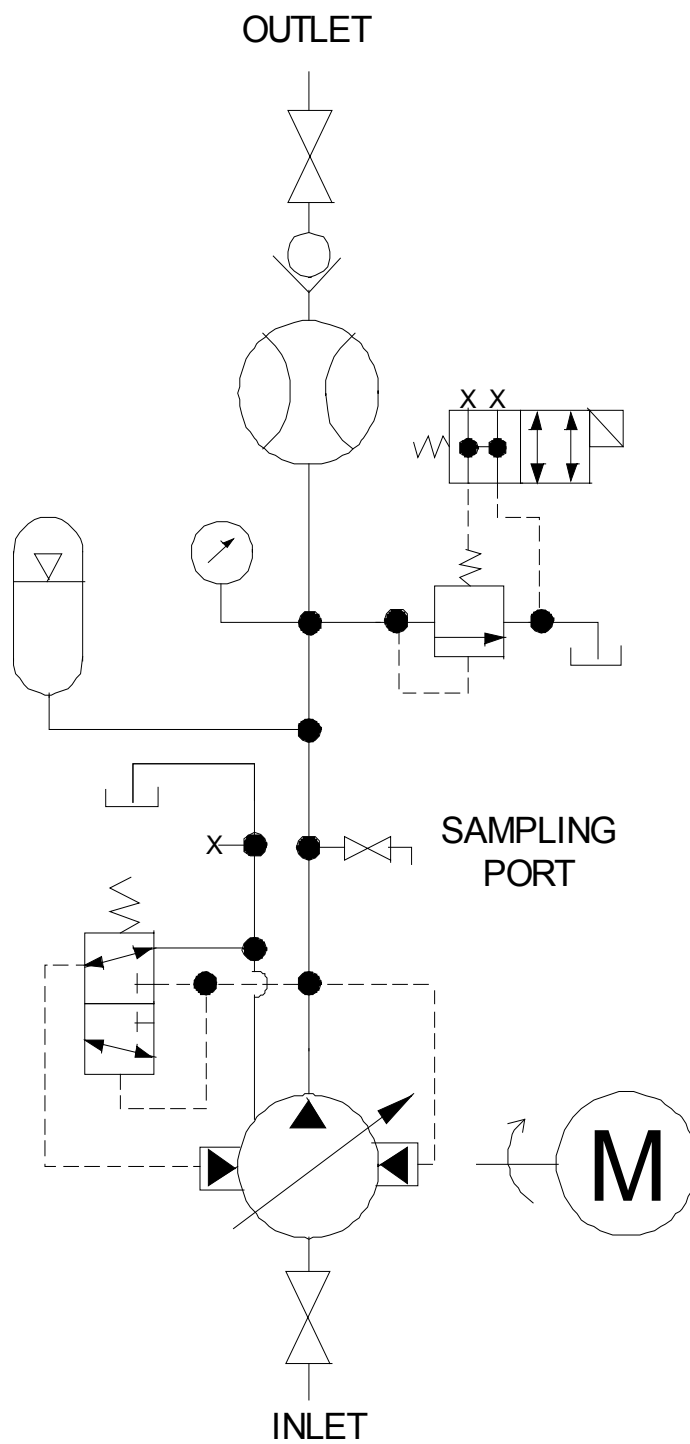


Each high pressure pump has an oil sampling port, shown to the left, used for gathering oil samples periodically. See the section on the **Oil Care Program** for more information.

### Depressurizing the Main Supply Lines

After the high pressure pumps are turned off, the distribution lines throughout the facility are still pressurized due to the check valve on the output of each pump. This pressure is removed by a solenoid valve which opens when the pumps are turned off. Pressurized oil in the main supply lines flows through a drain line and back to the reservoir.

# High Pressure Pump Schematic



## 4. Service Manifolds and Extenders

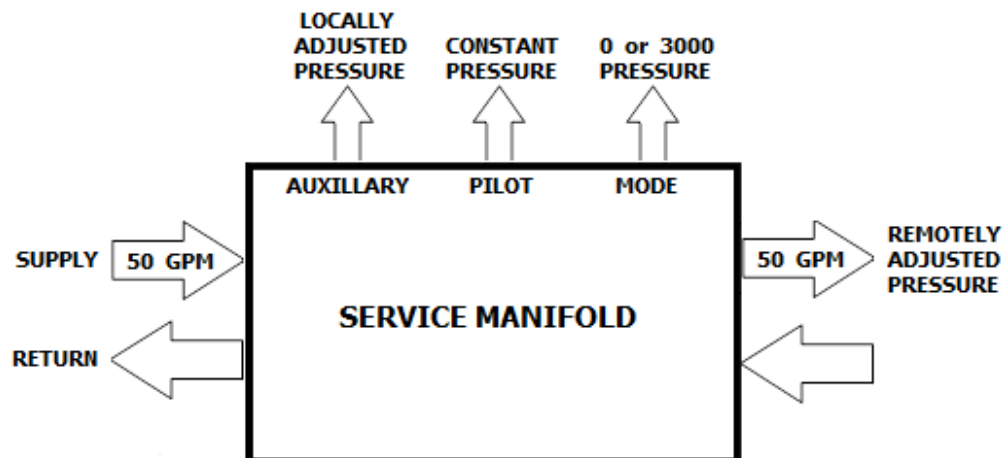
### OVERVIEW



A Service Manifold is an essential component of a load control system. A Service Manifold is used to interface each test site to the main hydraulic distribution lines. It allows multiple test sites to use a common fluid supply and operate at different pressures. It also provides safety functions such as a fast load abort to protect the test article and also provides auxiliary control functions to other devices in a small easily positioned package. It is normally used in conjunction with Servo Valve Manifolds or Controlled Abort Manifolds, but could be used in other ways as long as its operation is well understood.

All components in the Service Manifold are designed to operate at 3,000 PSI. It is sized so that a 1¼" hose or tube will supply the circuit. A 1¼" tube or hose can usually be made in-house. This allows custom lengths of tube or hose to be made on site to give better hydraulic system performance and a more aesthetic test setup. The primary flow output is a 1¼" port and auxiliary ports are ½".

A block diagram of the manifold connections is shown below. The Service Manifold input has two plumbing connections to the main supply and main return lines. It also has multiple output connections to each Servo Valve Manifold and/or to each Controlled Abort Manifold and one output to auxiliary devices.



## THEORY OF OPERATION

The Service Manifold is controlled by the test operator and the load control system. The Service Manifold has two modes of operation. It is either in **RUN** mode or **ABORT** mode. It has several functions which are briefly described below. More detailed operations are discussed in the section on **Component Functional Descriptions**.

The primary function of the Service Manifold occurs when it is in **RUN** mode. It passes fluid from the main supply line to the Servo Valve Manifolds and/or the Controlled Abort Manifolds at any desired pressure. An adjustable pressure allows for a safe or "soft" startup by starting a test at low supply pressure to the servo valves and gradually increasing that supply pressure until a stable control loop is established for each actuator. In contrast, the test can be shut down in a smooth controlled manner. The pressure is adjusted remotely by the test operator using the load control system.

A second function which is equally important occurs when the Service Manifold is switched to **ABORT** mode. When the mode is switched to **ABORT**, the primary output flow to the Servo Valve Manifolds is shut off very quickly and the pressure at the output is reduced to zero in approximately 25 milliseconds. See the performance curves in the section on **Performance Data**, Page 26. This feature is used when an unwanted anomaly such as an overload or mechanical failure of the test article occurs. This is usually done automatically by the control system, but it is good practice to also allow this to be done manually by pushing an **Emergency Stop** button. More on Emergency Stop Buttons can be found in Section 8.

There is an output port **MOD** used to indicate the current mode of the Service Manifold. When in **RUN** mode, the **MOD** output pressure will be 3,000 psi (whatever the main supply pressure is). When in **ABORT** mode, the **MOD** output pressure will be zero. This logical on/off signal is used to communicate to other connected manifolds which mode they are in. All attached manifolds have to be in the same mode at all times. In addition, the Service Manifold has an output port **PLT** that supplies constant pilot pressure that can be used by 5 port servo valves to supply

spool pressure. This port is unaffected by the operating mode. This Pilot remains at a constant high level even when the primary output flow is at a low pressure level. This pilot pressure will allow the servo valve to have improved performance when it is supplied with low supply pressures. Each servo valve which uses this port will consume a small amount of fluid and therefore the amount of fluid available to the primary output to the servo valves will be reduced by this amount.

Another important function of the Service Manifold is to filter the oil. All the oil supplied from the main supply line passes through a 10 micron filter before it reaches any other component. This feature will extend the life of all the components in the system and minimize the chances of component failure during testing.

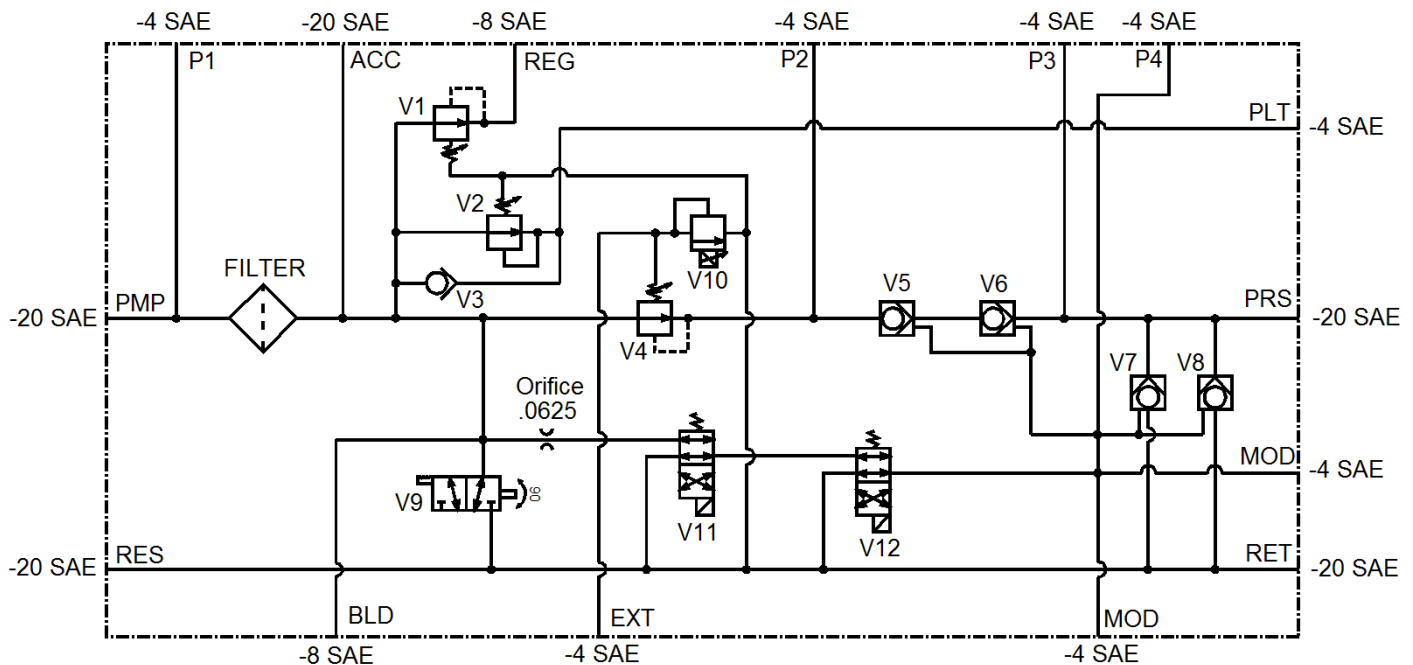
The Service Manifold also provides shock absorption during an abort. When an abort occurs, the flow is quickly blocked at the output. The fluid coming in at that time has some momentum which needs to be dissipated. If this doesn't happen, the components will experience a momentary pressure spike which could destroy them. The energy is dissipated by the accumulator in the circuit. The accumulator has an elastic bladder inside charged with a gas. The elastic bladder allows the incoming fluid to compress the gas to reduce the kinetic energy.

In addition, the Service Manifold provides an adjustable constant pressure source for auxiliary devices. This port is unaffected by the mode. This can be used for various functions. For example, you may need to secure a test fixture using hydraulic actuators. This port could supply pressure to one side of the actuators to provide a clamping force.

Finally, there are two other ports **BLD**, **EXT**, used to connect to a Service Manifold Extender which can increase the flow capacity of a test site. The **Service Manifold Extender** will be described later in this section.

## COMPONENT FUNCTIONAL DESCRIPTIONS

The following is a more detailed description of how the Service Manifold works. The function of each component is presented generally in the order in which the fluid flows through the circuit. Refer to the circuit schematic below as you read.



**Service Manifold Schematic**

Port **PMP** should be connected to the hydraulic pump or a common supply line. Port **RES** should be connected to the reservoir or common reservoir line. Fluid enters the Service Manifold through port **PMP** and passes through a 10 micron filter and then on to **V1, V2, V3, V4, V9**.

### **V9**

**V9** is a 3 Way Manual Valve used to bleed off pressure from the system when it is not in use.

### **V1**

**V1** is a pilot operated pressure reducing/relieving valve. **V1** is used to regulate the supply pressure from **PMP** to any pressure between 120 and 3,000 PSI. The **V1** output can only be set as high as the supply pressure at port **PMP**. The output of **V1** is accessed at port **REG** and intended to be used by auxiliary devices.

## **V2**

**V2** is also a pilot operated pressure reducing/relieving valve. **V2** is used to regulate the supply pressure from **PMP** to any pressure between 120 and 3,000 PSI. The **V2** output can only be set as high as the supply pressure at port **PMP**. The output of **V2** is accessed at port **PLT** and intended to be used by Controlled Abort Manifolds that use 5 port servo valves. This is supplied to the spool for better performance at low supply pressures. **PLT** is not used for 4 port servo valves.

## **V4, V10**

**V4** is a pilot operated pressure reducing valve controlled by **V10**, a proportional relief valve. The test operator can remotely send a variable electrical command signal to **V10** which varies the pilot pressure of **V4** which in turn varies the output pressure of **V4**. The output of **V4** can be varied from 100 PSI up to the supply pressure at **PMP**. **V4** requires a Parker "ED104" electronic driver board or equivalent to interface the test control panel to the valve. The output pressure of **V4** can be accessed at port **P2**.

## **V5, V6, V7, V8, V11, V12**

**V5** and **V6** are pilot-to-open check valves and **V7** and **V8** are pilot-to-close check valves. **V10** and **V11** are solenoid valves controlled by the test operator and/or the load control computer. When **V11** and **V12** are energized, they provide a pilot pressure to **V5**, **V6**, **V7**, and **V8**. A pilot pressure at **V5** and **V6** will open them to allow flow through the Service Manifold. A pilot pressure at **V7** and **V8** will close them to prevent flow from the main flow path to the system return line. When **V11** and **V12** are de-energized, the pilot pressure to **V5** and **V6** is ported to return causing **V5** and **V6** to close and the flow through them to be shut off. At the same time, the loss of pilot pressure at **V7** and **V8** causes them to open and the pressure at **PRS** to bleed to zero.

## **V3**

**V3** is a check valve used to bleed the pressure from the Pilot line when the Service Manifold is shutdown.

## **Redundancy**

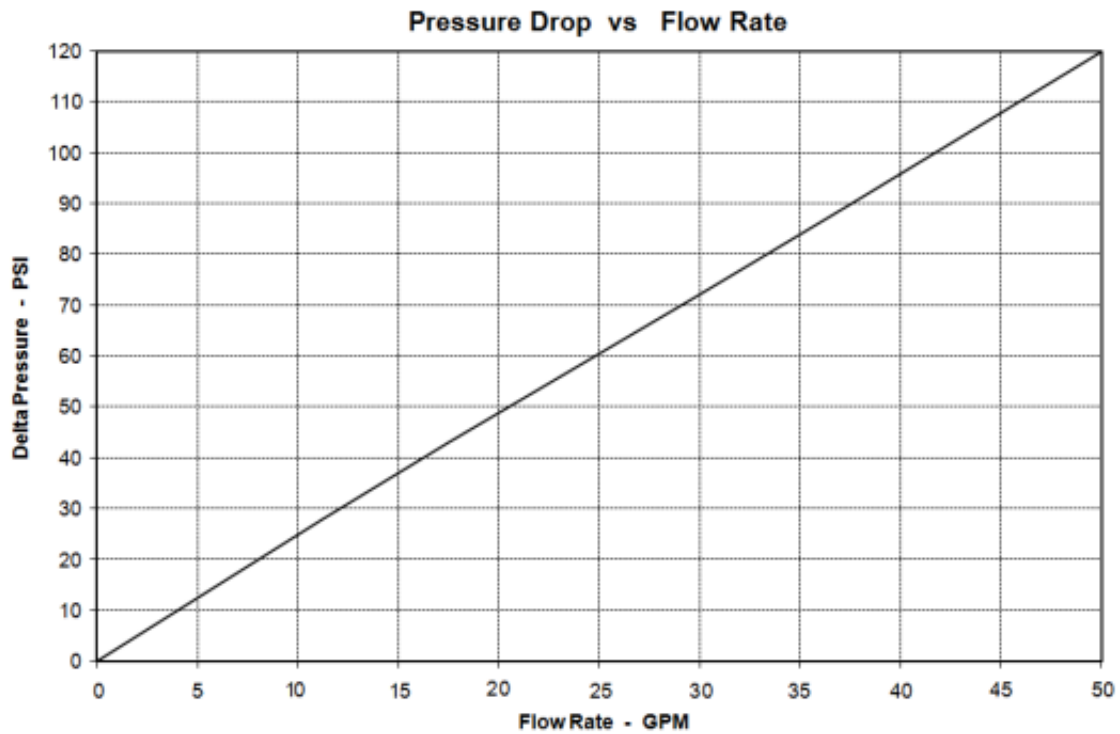
Since it is critical that the Service Manifold is very reliable and operate correctly, all the vital valves have a redundant counterpart. **V5** and **V6** are shutoff valves plumbed in series for redundancy. **V7** and **V8** are bleed valves in parallel for

redundancy. **V11** and **V12** are logic valves in series. If either one in the pairs of valves would fail, the other one would allow the overall circuit to still perform its intended function.

## PERFORMANCE DATA

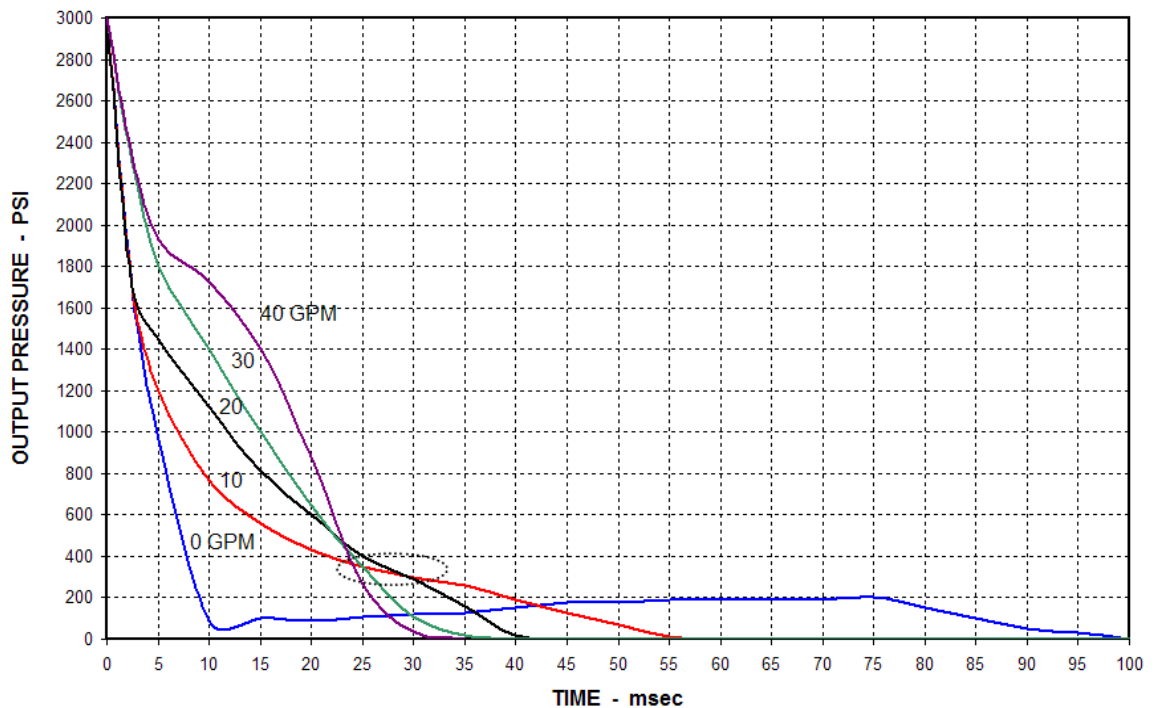
### Pressure Drop vs Flow

The graph below shows the pressure drop across the Service Manifold as a function of flow rate. The pressure drop is the pressure difference measured at the main inlet port **P1** and at the outlet port **P3**. This curve is based on a clean filter element.



**Fast Load Abort**

Fast load abort is an important measure of performance and critical for a safe load test. The figure below shows the time to reduce the pressure at the output ports **PRS** to zero when operating at various flow rates. It can be seen that regardless of the flow rate, the output pressure is reduced to about 10% in about 25 milliseconds. The supply pressure for these measurements is 3,000 PSI. Output pressure is measured at **P3**.

**Fast Load Abort Time**

## **INSTALLATION**

The information contained in this section pertains to new installations and to Service Manifolds which have been removed from a system for reconfiguration or repair. The manifold block has labels stamped near each valve and port location.

### **Site Preparation**

Site selection for a Service Manifold (SM) should take into account the following considerations:

1. The SM must be installed in an area where it is protected from extreme temperature and humidity conditions. Limit conditions are 40° to 125° F and 20 to 80% humidity. A normal shop or laboratory with a non-corrosive atmosphere is recommended.
2. A minimum floor space of 4 ft by 4 ft is required for each SM. This will provide space for hydraulic connections and service access. Additionally a 6 ft vertical clearance is recommended for service access.
3. The SM should be located as close as possible to the servo valves it supplies.

Once a site has been selected that meets the above criteria, move the SM to its proper location and secure it in place by locking the cart wheels. Then perform the applicable procedures from the following paragraphs.

### **Conversions for 115VAC or 24 VDC operation**

The functions of the SM are controlled by two solenoid activated valves. These valves are available in either 24 Volt DC or 115 Volt AC versions. Field exchange of a solenoid valve is explained in the "Solenoid Valve Exchange" section. Load abort times may be affected when switching between AC and DC valve versions.

### **Electrical cable Connections**

Connectors for 24 VDC valves are the same as 115 VAC valves. However, changing the solenoids will require changes to the control unit or control panel.

**Hydraulic line  
Connections**

**Appendix A** page 3 illustrates the most common configuration of a Service Manifold (SM) connected to one or more Servo valve Manifolds or Controlled Abort Manifolds. Connections from the hydraulic power supply to the SM **PMP** port and to the SM **RES** port can be up to 1¼" hose or tube. Connections from the Service Manifold to Servo valve Manifolds or Controlled Abort Manifolds will depend on the test requirements. The **PRS**, **RET**, and the **MOD** ports will always need to be connected. The **PRS** and **RET** line sizes will be based on the flow requirements. The **MOD** line only carries a static pressure and no flow, so it can always be ¼". The **PLT** line is only used when 5 port servo valves are required. See the section on **Servo Valves** for more information on choosing 4 port or 5 port servo valves. The **PLT** line carries a small flow rate, so it can usually be ¼" also unless the servo valves are leaking excessively internally.

**SYSTEM CHECKOUT**

This following is a procedure for checking the installation of the Service Manifold (SM). The procedure assumes that the unit has been installed on a site which meets the criteria specified in **Site Preparation**, applicable valve conversions have been made, and appropriate electrical and hydraulic connections have been made.

1. Check that the SM cart wheels are locked.
2. Check all hydraulic connections against the system diagrams. Ensure that the connections are tight.
3. Check all electrical cable connections against the system diagrams. Ensure that the connections are correctly mated and locked.
4. Open the main hydraulic supply valve and check the **P1** gauge for supply pressure. If supply pressure matches pump output pressure continue with checkout. The output **P3** pressure should be zero at this time. Check pilot pressure gauge for an arbitrary high level pressure. Check for any oil leaks.
5. Set the command voltage to the variable relief valve, **V10**, to zero.
6. Adjust Pressure Reducing/Relieving Valve **V4** to the minimum output – this should be approximately 120 PSI. See the section on **Setting the Minimum PRS Output Pressure** for adjustment procedure.
7. Enable the SM by energizing **V11** and **V12**. The output pressure **P3** should still be at or near zero. Again, check for any oil leaks.
8. Increase the command voltage to the variable relief valve, **V10**, and watch to see if the output pressure **P3** increases. When the command voltage is at 10 volts, the output pressure can be adjusted to the maximum output pressure expected at ports **PRS**. See the section on **Setting the Maximum PRS Output Pressure** for adjustment procedure. Cycle the output pressure up and down several times to remove air from the system.

Again, check for any oil leaks.

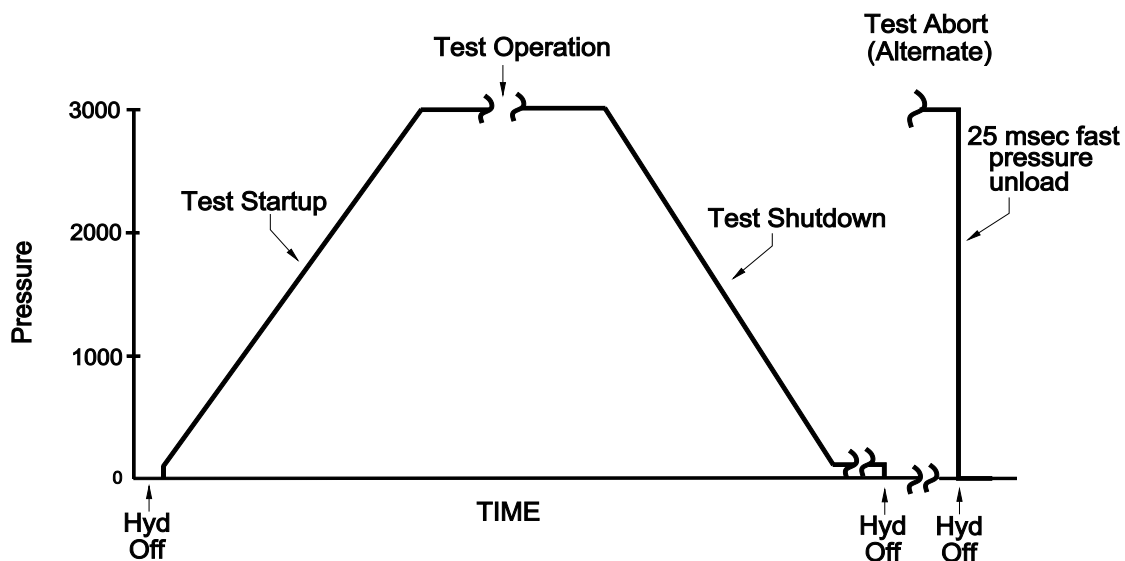
9. Decrease the command voltage to the variable relief valve, **V10**, to about 20% of maximum output pressure. Perform a fast load abort by de-energizing all valves simultaneously. The output pressure, **P3**, and the **MOD** pressure should both drop to zero very fast (approximately 25 milliseconds or less). The pilot pressure should remain at the previous level.

## OPERATION

The Service Manifold (SM) is very simple to operate. The figure below illustrates the remotely controlled output pressure **PRS** profile during a typical test operation.

### Operation Sequence

The sequence of events starts with the SM turned off. When the SM is turned off, there should be no power to any of the valves. The next event is to turn on the SM. The SM is turned on by energizing **V11** and **V12** simultaneously. The **PRS** output pressure will rise to about 120 PSI. This is a minimum pressure output. At this time the command voltage to **V10** should be at or near 0 volts. When the test operator is ready to start the test, the voltage to **V10** should be ramped up to get the desired output pressure level. The SM will now continue to maintain the desired output pressure at **PRS**. When the test is ready for shutdown, the test operator ramps down the command voltage of **V10** to zero to reduce the output pressure **PRS** to about 120 PSI. The next step is to turn off the SM by de-energizing **V11** and **V12**. When this is done the output pressure should be at zero PSI. An alternate method of shutting off pressure is a fast load abort. This is accomplished by de-energizing all valves simultaneously.



### Setting the REG Output Pressure

The pressure at the **REG** port is controlled by Pressure Reducing/Relieving Valve **V1**. The pressure at port **REG** can be varied by changing the screw adjust of **V1**. Loosen lock nut and use a 1/4" hex head wrench to change the pressure setting. To increase the output pressure, turn the screw adjust clockwise. To decrease the output pressure, turn the screw adjust counterclockwise. After making the adjustment, tighten the lock nut.

**V1** also acts as a relief valve, relieving any shocks or surges that occur between the **REG** port and the device connected to **REG**. When **V1** is in relieving mode the inlet port is blocked.

### Setting the minimum PRS Output Pressure

The minimum **PRS** output pressure is set by adjusting Pressure Reducing/Relieving valve **V4**. Before making an adjustment, make sure the command voltage to **V10** is zero. Loosen the lock nut and use a 5/32" hex head wrench to adjust **V4**. To decrease the output pressure, turn the adjustment counter clockwise. After making an adjustment, tighten the lock nut.

### Setting the maximum PRS Output Pressure

The pressure level of the main flow path is variable and set by the test operator at the test site control panel. The pressure of the output pressure at port **PRS** is controlled by valves **V4** and **V10**. **V4** is a Pilot Operated Pressure Reducing Valve controlled by **V10**, a Proportional Relief Valve. The test operator can remotely send a variable electrical command signal to **V10** which varies the pilot pressure of **V4** which in turn varies the output pressure of **V4**. The output pressure of **V4** can be varied from 120 PSI up to the SM **PMP** supply pressure. **V10** requires an "ED104" electronic driver board to interface the test control panel to the valve.

Before setting the maximum output pressure, the minimum output pressure should have already been set. If not, go to the previous paragraph and follow the instructions for setting the minimum output pressure setting.

After the minimum output pressure has been set, apply the maximum command voltage to **V10**. With the voltage

applied to **V10**, loosen the lock nut and use a 6 mm hex head wrench to adjust **V10**. To increase the pressure, turn the adjustment clockwise. To decrease the pressure, turn the adjustment counter clockwise. After making the adjustment, tighten the lock nut.

### Setting the Pilot Pressure

The Service Manifold (SM) has a pilot pressure port **PLT** which provides a constant source of flow to 5 port servo valves. The pilot pressure level can be varied by loosening the lock nut and using a 1/4" hex head wrench to change the screw adjust of **V2**. To increase the pilot pressure, turn the screw adjust clockwise. To decrease the pilot pressure, turn the screw adjust counterclockwise. After an adjustment has been made, tighten the lock nut.

### Fast Pressure Unloading

The flow out of port **PRS** can be shut off very quickly and the pressure at port **PRS** is reduced to zero in approximately 25 milliseconds. See the performance curves in the section on **Performance Data**. This feature is used when an unwanted anomaly such as an overload on a test article occurs. To perform a fast pressure unload, **V11** and **V12** must be de-energized and the command voltage to **V10** should be set to zero. All valves must be de-energized simultaneously. This is usually done automatically by the control system, but it is good practice to also allow this to be done manually by pushing an "Emergency Stop" button.

## PERIODIC MAINTENANCE

### Filter Maintenance

The filter does not normally require special attention except for periodic monitoring of the differential pressure indicator. Schedule replacement of the filter element every six months or sooner, and have ample supply of spare elements available.

#### **WARNING!**

FAILURE TO DEPRESSURIZE THE FILTER BEFORE SERVICING THE ELEMENT COULD RESULT IN EXPLOSIVE LOSS OF FLUID, DAMAGE TO EQUIPMENT, AND POSSIBLE PERSONAL INJURY.

### Changing the Filter Element



The element needs to be changed when the differential pressure indicator moves from green to yellow.

Turn off and depressurize the system. Unscrew and remove cover from tube and head assembly, counterclockwise when viewed from above. It may be necessary to use a correct sized wrench on the hexagon on the top of the cover to loosen the cover initially.

Remove filter element and carefully inspect the surface for visible contamination. Normally no dirt should show. Visible dirt or particles can be an early warning of system component breakdown and can indicate potential failure. Discard both the filter element and its O-rings.

**The filter element is NOT CLEANABLE.** Any attempt to clean the filter element can cause degradation of the filter medium and allow contaminated fluid to pass through the filter element.

**WARNING! DO NOT ATTEMPT TO CLEAN OR REUSE ELEMENT.**

DO NOT run the SM without a filter element installed. Check that the O-ring on the cover is not damaged. Use replacement filter element part number called for on the filter tube.

Lubricate element O-ring with clean system fluid and push open end of filter element straight onto the nipple in the head assembly. Lightly lubricate the threads of the cover with clean system fluid. Screw cover onto tube until it bottoms.

**O-RING SEALING IS NOT IMPROVED BY OVER TIGHTENING**

### Accumulator Maintenance

Little maintenance is required for a bladder accumulator. If there is external leakage, tighten all connections. If leakage continues, remove accumulator from the system and replace the faulty components.

### Pre-charge Checking

After original installation, check pre-charge once during first week to see that no leak has developed. Thereafter, check pre-charge monthly. The bladder should have a gas pressure of approximately 2,000 PSI. If pre-charge is low, check gas valve for leakage and recharge.



Use only an inert gas such as nitrogen for pre-charging the accumulator. It is recommended to use a Charging and Gaging Assembly. If other equipment is used, make sure it is compatible with the gas valve assembly and nitrogen source.

1. Discharge all oil from accumulator.
2. Attach gaging assembly to gas valve on accumulator
3. Check gas pressure. The gas pressure will be determined by the particular application.
4. Remove gaging assembly.

### **Removing an Accumulator**

Shut equipment down and make certain that hydraulic pressure at the accumulator is at zero by turning the knob on **V9** on the Service Manifold and read pressure on **P1** gauge.

1. Remove gas valve guard and gas valve cap.
2. Attach gaging assembly to accumulator.
3. Open bleed valve and release all the gas pressure.
4. Remove accumulator from hydraulic system.

### **Solenoid Valve Exchange**

This procedure describes the process for removing and replacing a manifold solenoid valve. Equipment required includes a 5/32" hex head wrench and a replacement solenoid valve.

1. Make sure the hydraulic system is depressurized.
2. Turn off the electrical power to the valve.
3. Disconnect the electrical control cable connector from the appropriate solenoid valve.

Remove the solenoid from the manifold block by loosening the four cap screws and taking them out.

4. Coat the O-rings of the replacement solenoid valve with clean hydraulic fluid and mount it using the alignment pin to position it.
5. Replace the four cap screws and tighten them.
6. Replace the control cable connector.

### **Cartridge Valve Exchange**

This procedure describes the process for removing and replacing a cartridge valve. Equipment required includes an adjustable open end wrench and the appropriate replacement cartridge valve.

1. Make sure the hydraulic system is depressurized.
2. Remove the cartridge valve by unscrewing it with the adjustable open end wrench.
3. Coat a new cartridge valve with clean hydraulic fluid. Insert the cartridge into the SM unit and tighten it.

### **Exchanging a Proportional Relief Valve**

This procedure describes the process for removing and replacing the Proportional Relief Valve (V10). Equipment required includes a 5/32" hex head wrench and a replacement valve.

1. Make sure hydraulic system is depressurized.
2. Turn off the electrical power to the valve.
3. Disconnect the electrical control cable connector from the proportional valve (V10).
4. Remove the proportional valve from the manifold block by loosening the four cap screws and taking them out.
5. Coat the O-rings of the replacement proportional valve with clean hydraulic fluid.
6. Replace the four cap screws and tighten them
7. Replace the control cable connector.

**PARTS BREAKDOWN**

COMPONENT	DESCRIPTION	MANUFACTURER	PART #
V1	Direct Acting Pressure Reducing Valve	Sun	PRFB-LAN
V2	Direct Acting Pressure Reducing Valve	Sun	PRFB-LAN
V3	Check Valve	Sun	CXED-XCN
V4	Pilot Operated Pressure Reducing Valve	Sun	PBJB-LAN
V5	Pilot to Open Check Valve	Sun	CKIB-XCN
V6	Pilot to Open Check Valve	Sun	CKIB-XCN
V7	Pilot to Close Check Valve	Sun	COHA-XCN
V8	Pilot to Close Check Valve	Sun	COHA-XCN
V9	3 Way Manually Operated Spool Valve	Sun	DMDM-LAN
V10	Proportional Relief Valve	Parker	DSAE1007P07GLAF
V11	Directional Flow Control Valve	Parker	D1VW20BNJWF
V12	Directional Flow Control Valve	Parker	D1VW20BNJWF
Accumulator	1 gallon bladder accumulator	Parker	
Filter	10 micron filter	Parker	50P 1 10Q ML 50XX
Manifold	Aluminum black anodized	Damon	E-28801

**SERVICE MANIFOLD SPECIFICATION SUMMARY**

Pressure Rating                      3,000 PSI  
Flow                                      50 GPM  
Weight                                    200 lbs

## Electrical

## Valves

Solenoid            (2)    110 VAC    1.5 Amp  
Proportional       (1)    0 – 10 VDC   1 Amp

## Transducers

Pressure            (4)    4 – 20 ma

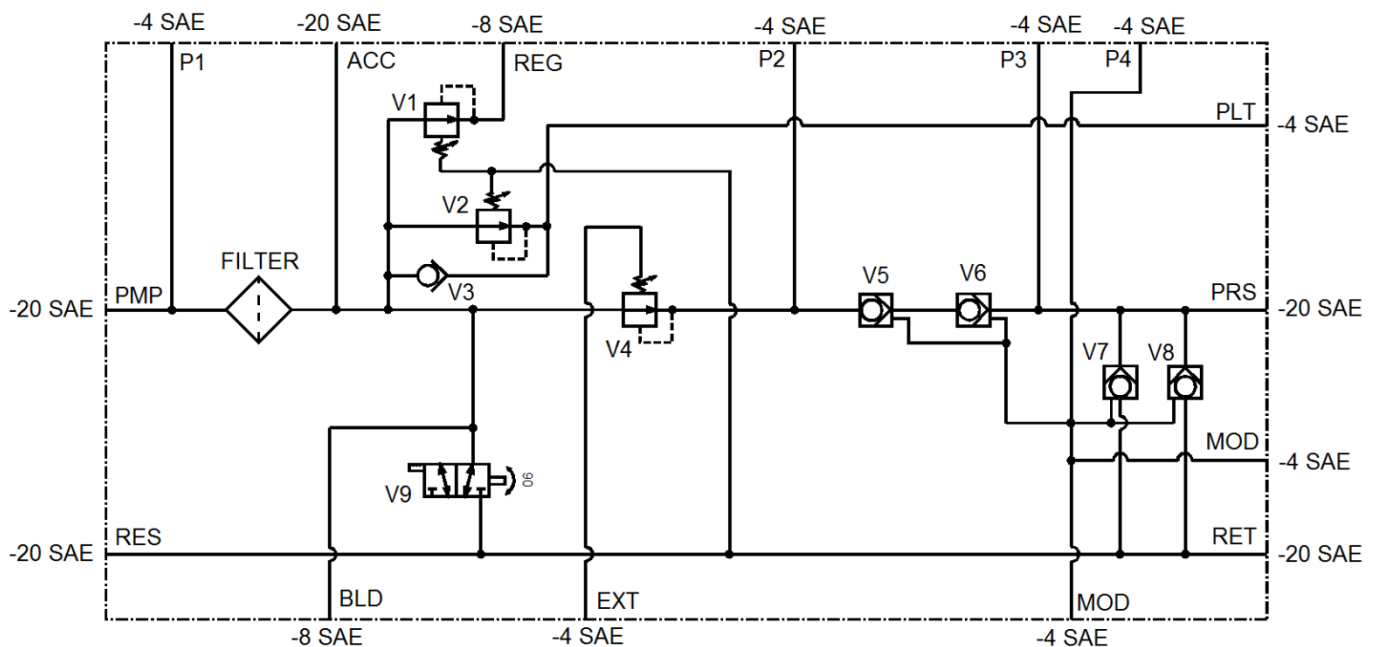
## SERVICE MANIFOLD EXTENDER



The Service Manifold Extender is very similar to the Service Manifold described above. Its purpose is to add flow capacity to a test. The Service Manifold extender adds 50 GPM to the overall flow rate to the test site. It differs in the way it is controlled. The Service Manifold Extender must be used with a Service Manifold. The Extender is controlled by the original Service Manifold through hydraulic connections. No electrical connections are required.

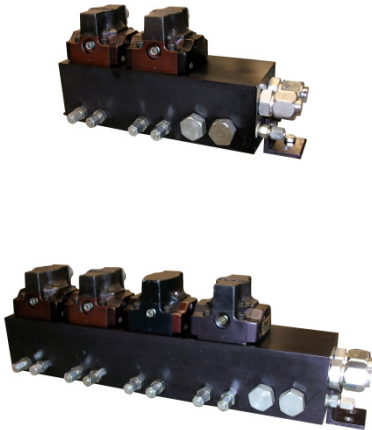
The schematic of the Service Manifold Extender is shown below. The **PMP** port should be connected to a pump or common supply line. The **RES** port should be connected to the reservoir or common reservoir line. The **EXT**, and one of the **MOD** ports must be connected to the corresponding ports on the Service Manifold. The **BLD** port can be connected to the **BLD** port on the Service Manifold to allow both manifolds to be depressurized at the same time. These **EXT**, **MOD**, and the **BLD** lines will provide the control signals it needs to duplicate the original Service Manifold output.

The installation, operation, and maintenance is very similar to the Service Manifold. There are no electrical valves to setup or control. For any other information on using the Extender see the previous information in this section.



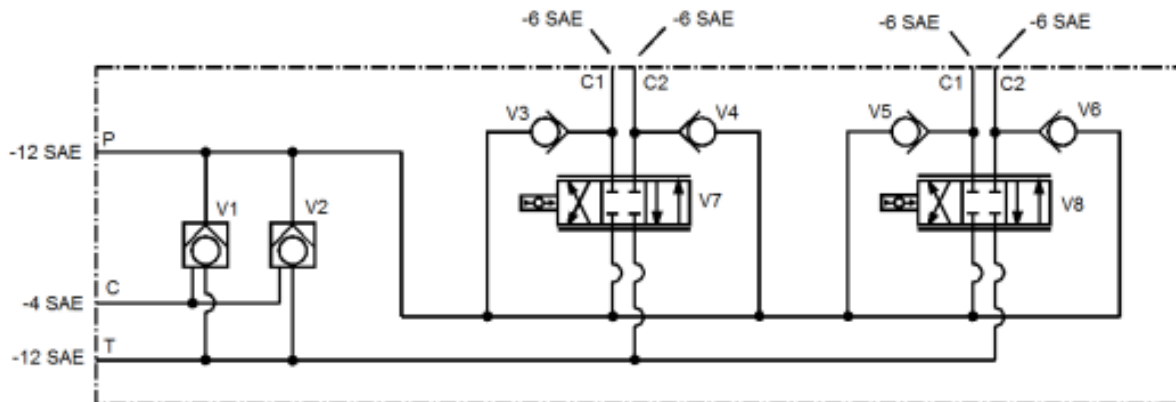
## 5. Servo Valve Manifolds

### OVERVIEW



Servo Valve Manifolds are used to simplify the plumbing when using multiple servo valves and cylinders. They also provide safety functions such as a redundant means of bleeding pressure to protect the test article. They are always used in conjunction with a Service Manifold. Multiple Servo Valve Manifolds may be connected to a single Service Manifold. There are two Servo Valve Manifold models which function the same way. One holds two servo valves and the other holds four servo valves. There are blocking plates that can be substituted for a servo valve in the case where only one or three servo valves are needed.

All components in the Servo Valve Manifolds are designed to operate at 3,000 PSI. A schematic of the manifold is shown below for a two place manifold.



### Hydraulic Connections

The Servo Valve Manifold has three connections to the Service Manifold. The input **P** supply line is connected to the Service Manifold **PRS** output port.

The **T** output line is connected to the Service Manifold **RET** port or it could bypass the Service Manifold as long as it connects to the building main return line. The **C** port is connected to the Service Manifold **MOD** port.

There are pairs of ports labeled **C1** and **C2** for each servo valve. These are connected to actuators – usually cylinders. The **C1** port is connected to the compression end of the cylinder and the **C2** port is connected to the tension end of the cylinder. The compression end is defined as the end which pressure would put the cylinder rod in compression and the tension end is defined as the end which pressure would put the cylinder rod in tension.

### THEORY OF OPERATION

The Servo Valve Manifold has two modes of operation. It is either in **RUN** mode or **ABORT** mode. All Servo Valve Manifolds have to be in the same mode at all times.

Each manifold has two pilot operated check valves **V1, V2** which can directly connect the input pressure line **P** to the output return line **T**, therefore bypassing the servo valves. Since these check valves are critical to the operation of the manifold, they are in parallel to provide redundancy in the event one of them would fail. If one of them failed, the manifold would still perform its intended function.

### RUN Mode

In **RUN** mode, a pressure at the **C** port from the Service Manifold causes the pilot operated check valves **V1** and **V2** to close the connection between the **P** and **T** lines. Fluid flows from the **P** port then goes to valves **V3, V4, V5, V6** and stops at each of these points because the flow is checked.

Fluid also flows to servo valves **V7** and **V8** supply ports. The servo valves direct the fluid to either the **C1** or **C2** port depending on the polarity of the electrical input signal from the control system or some other device. If fluid flows from the servo valve supply port to the **C1** port, then at the same time, fluid flows from **C2** to the servo valve return port and then out the manifold **T** port. On the other hand if fluid flows from the servo valve supply port to the **C2** port, then fluid flows from the **C1** port to the servo valve return port then out the manifold **T** port.

## **ABORT Mode**

In **ABORT** mode, the pressure at the **MOD** port is removed by the Service Manifold and causes the pilot operated check valves **V1** and **V2** to open and connect the **PRS** port directly to the **RET** port. When the Service Manifold is in **ABORT** mode, it also shuts off the flow to the Servo Valve Manifold **PRS** input. This combination of actions provides multiple layers of redundancy in removing flow and pressure to the servo valves. At the same time this is happening, check valves **V3**, **V4**, **V5**, and **V6** allow the pressure on both ends of the cylinders to escape to the **RET** port to remove all load from the test article.

## **INSTALLATION**

The information contained in this section pertains to new installations and to Servo Valve Manifolds (SM) which have been removed from a system for reconfiguration or repair. If the unit is not completely assembled see the illustrated parts breakdown information at the end of this section. The manifold block has labels stamped near each valve and port location.

The SM must be installed in an area where it is protected from extreme temperature and humidity conditions. Limit conditions are 40° to 125° F and 20 to 80% humidity. A normal shop or laboratory with a non-corrosive atmosphere is recommended.

The SM should be located as close as possible to the actuators it supplies.

Provisions should be made to mount the SM to prevent movements due to hydraulic line transients. The SM may be mounted to steel framework. Ideally, the SM would be mounted in an elevated position to allow for a drip pan during service.

**Appendix A** page 3 illustrates the most common configuration of a Service Manifold connected to one or more Servo Valve Manifolds. Connections from the Service Manifold to Servo Valve Manifolds will depend on the test requirements. The **P**, **T**, and the **C** ports will always need to be connected. The **P** and **T** line sizes will be based on the flow requirements.

The **C** line only carries a static pressure and no flow, so it can always be ¼"

## MAINTENANCE

Servo Valve Manifolds require little maintenance. It is recommended that the manifolds be dismantled after the conclusion of each test. The cartridge valves should be inspected for any wear and either discarded or stored for later use. The cartridge valves are not repairable. The servo valves should be stored properly for later use. The manifold block should be cleaned in the parts washer, dried, and wrapped to be stored for later use.

## PARTS BREAKDOWN

COMPONENT	DESCRIPTION	MANUFACTURER	PART #
V1	Pilot to Close Check Valve	Sun	COFA-XAN
V2	Pilot to Close Check Valve	Sun	COFA-XAN
V3	Check Valve	Sun	CXCB-XAN
V4	Check Valve	Sun	CXCB-XAN
V5	Check Valve	Sun	CXCB-XAN
V6	Check Valve	Sun	CXCB-XAN
V7	Servo Valve	Moog	76, 760 Series
V8	Servo Valve	Moog	76, 760 Series

## SERVO VALVE MANIFOLD SPECIFICATION SUMMARY

Pressure Rating	3,000 PSI
Flow	15 GPM per channel 20 GPM per manifold
Weight	40 lbs.

## 6. Controlled Abort Manifolds

### OVERVIEW



Controlled Abort Manifolds have similarities to Servo Valve Manifolds. Controlled Abort Manifolds are used to simplify the plumbing when using multiple servo valves and cylinders. They differ by accepting either 4 or 5 port servo valves and providing additional safety functions such as regulating the supply pressure to each servo valve, limiting the maximum pressure to each side of the actuators, and regulating the displacement rate of the actuator on abort. Each of the functions will be described in further detail in the section **Theory of Operation**.

Controlled Abort Manifolds are always used in conjunction with a Service Manifold. Multiple Controlled Abort Manifolds may be connected to a single Service Manifold. Each manifold is designed for three servo valves, but there are blocking plates that can be substituted for a servo valve in the case where only one or two servo valves are needed.

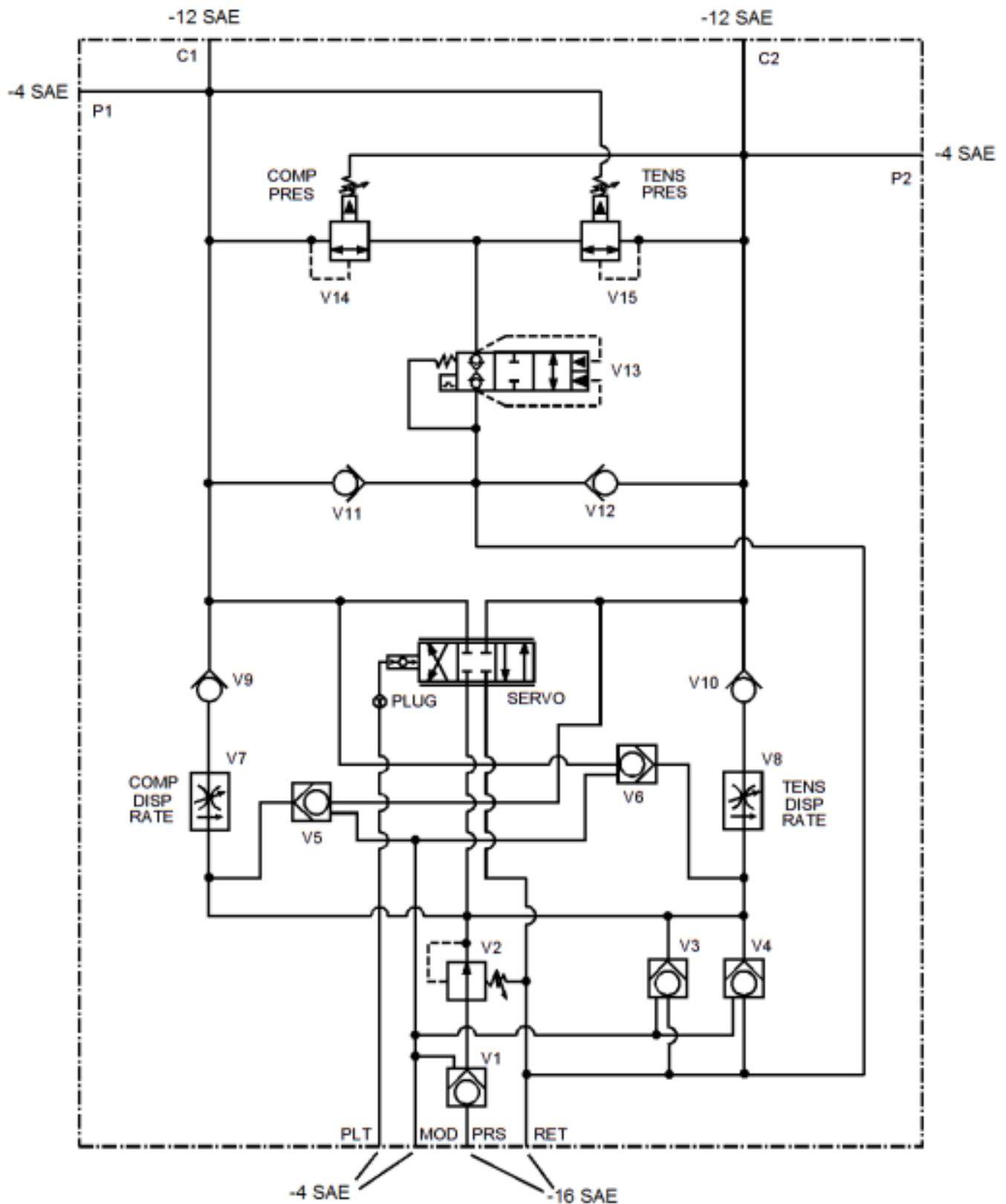
### 4 or 5 port servo valves

The Controlled Abort Manifolds can be used with either 4 port servo valves or 5 port servo valves. The choice of using 4 or 5 port servo valves depends on the pressure required to achieve the load for that channel. 5 port servo valves should always be used when a low supply pressure is used to apply a load. This will provide better control than if a 4 port servo valve is used with a low supply pressure. But a 5 port servo valve can also be used with a high supply pressure.



When using 5 port servo valves, be sure to remove the plug to the pilot port for that channel. Conversely, when using 4 port servo valves, be sure the plug is installed in the pilot port. The plug for each channel is located inside the manifold. To access one, first remove the outer construction plug for that channel. See the schematic and photo to the left for details.

A full schematic of the manifold is shown in Appendix B. A schematic of a single channel is shown on the next page.



## Hydraulic Connections

The Controlled Abort Manifold has four connections to the Service Manifold.

The **PRS** port is connected to the Service Manifold **PRS** port.  
 The **RET** port is connected to the Service Manifold **RET** port.  
 The **MOD** port is connected to Service Manifold **MOD** port.  
 The **PLT** port is connected to the Service Manifold **PLT** port.

There are pairs of ports labeled **C1** and **C2** for each servo valve. These are connected to actuators – usually cylinders. The **C1** port is connected to the compression end of the cylinder and the **C2** port is connected to the tension end of the cylinder. The compression end is defined as the end which pressure would put the cylinder rod in compression and the tension end is defined as the end which pressure would put the cylinder rod in tension.

## THEORY OF OPERATION

The Controlled Abort Manifold has two modes of operation. It is either in **RUN** mode or **ABORT** mode. All Controlled Abort Manifolds have to be in the same mode at all times.

Each manifold has three load control channels which perform multiple functions such as regulating the supply pressure to each servo valve, limiting the maximum pressure to each side of the actuators, and regulating the displacement rate of the actuator on abort. Each channels' functions operate independently, but all three channels' mode is controlled by two pilot operated check valves **V16** and **V17**. Since these check valves are critical to the operation of the manifold, they are in parallel to provide redundancy in the event one of them would fail. If one of them failed, the manifold would still perform its intended function.

## RUN Mode

In **RUN** mode, a pressure at the **C** port from the Service Manifold causes the pilot operated check valves **V16** and **V17** to close the connection between the **PRS** and **RET** lines and opens the **V1** check valve in each channel and also closes check valves **V3** and **V4** in each channel. Fluid flows from the **PRS** port then goes through valve **V1**, through pressure regulator **V2**, through **V7**, **V8** and stops at each

of these points because the flow is checked by **V9** and **V10**.

The servo valves direct the fluid to either the **C1** or **C2** port depending on the polarity of the electrical input signal from the control system or some other device. If fluid flows from the servo valve supply port to the **C1** port, then at the same time, fluid flows from **C2** to the servo valve return port and then out the manifold **RET** port. On the other hand if fluid flows from the servo valve supply port to the **C2** port, then fluid flows from the **C1** port to the servo valve return port then out the manifold **RET** port.

### Setting the Channel Supply Pressure

Each channel can have the supply pressure to the servo valve inlet set to any value between 100 and 3000 PSI (pump pressure max). Pressure regulator **V2** can be adjusted to the maximum pressure needed for the maximum load of that particular channel. This allows the use of an actuator that is oversized to be used. For example, if a test requires a load to failure that is twice as much as the normal cycling load, then the supply pressure can be adjusted to match the actuator areas without changing the actuator and mounting fittings. This allows the channel to run the normal cycling pressure at a safer level in case of a control system or servo valve failure.

### Setting the Maximum Load Limits

Each channel can limit the maximum load for tension and compression independently. Valves **V14** and **V15** are sequence valves which sense the differential pressures across the actuator. The spring setting should be set to the pressure needed to achieve the maximum load for that channel direction. **V14** limits the maximum load for the compression direction and **V15** limits the maximum load for the tension direction.

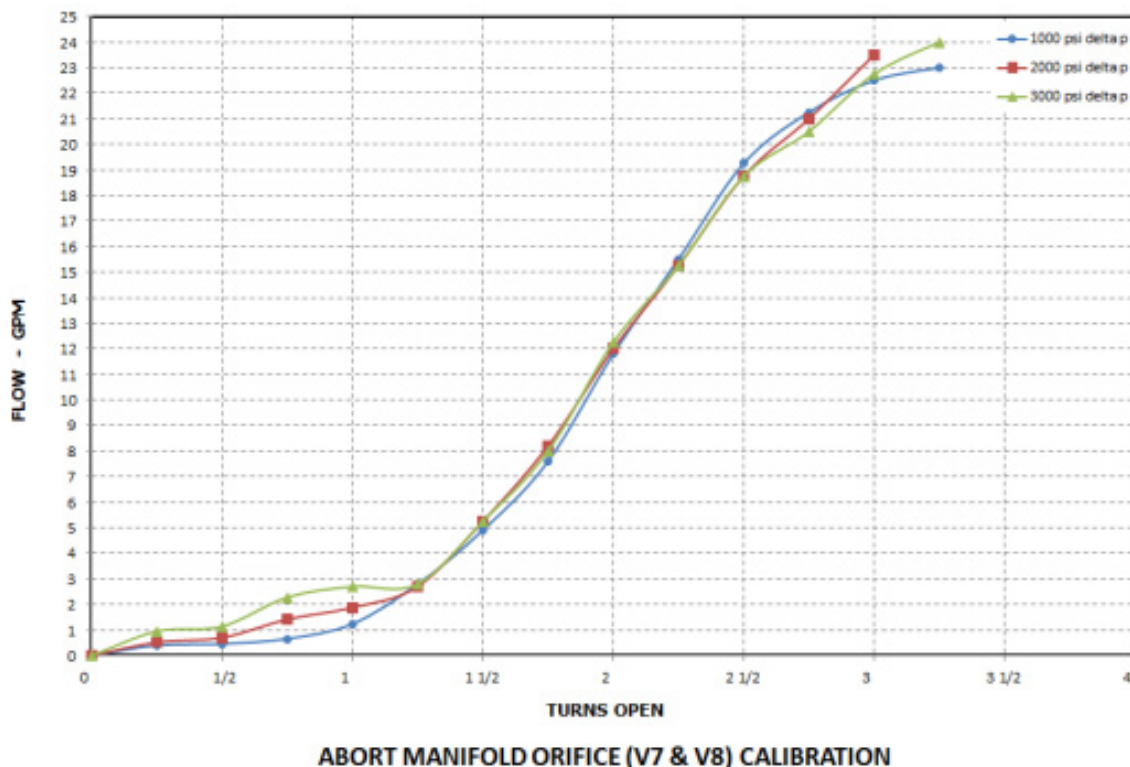
### ABORT Mode

In **ABORT** mode, the pressure at the **MOD** port is removed by the Service Manifold and causes the pilot operated check valves **V16** and **V17** to open and connect the **PRS** port directly to the **RET** port. When the Service Manifold is in **ABORT** mode, it also shuts off the flow to the Controlled

Abort Manifold **PRS** input. This combination of actions provides multiple layers of redundancy in removing flow and pressure to the servo valves. At the same time this is happening, check valves **V9**, and **V10** allow the pressure on both ends of the cylinders to escape through orifices **V7** and **V8**. Valve **V5** and **V6** allow the fluid to flow into the opposite side of the cylinder. Valves **V3** and **V4** allow any excess fluid to go to return. **V11** and **V12** prevent any cavitation on either side of the cylinder by taking needed fluid from the return line.

### Controlling the Cylinder Displacement Rate on Abort

Sometimes it is important to control the cylinder displacement rate on abort to prevent unnatural stresses on the test article. The displacement rate can be controlled by adjusting the orifice settings of **V7** for the compression direction and **V8** for the tension direction. The final orifice settings will usually need to be set by trial and error, but an initial setting can be calculated using the cylinder area and the desired speed of the of the test article going back to its neutral position. The following chart shows the orifice setting for a given flow rate.



## Overload Indicator

Valves **V14** and **V15** limit the pressures, and therefore load, in the compression and tension directions respectively. Valve **V13** is actually a flow switch which indicates if **V14** or **V15** is relieving. **V13** can be used to alarm the operator if an overload is occurring at any time.

## INSTALLATION

The information contained in this section pertains to new installations and to Servo Valve Manifolds (SM) which have been removed from a system for reconfiguration or repair. If the unit is not completely assembled see the illustrated parts breakdown information at the end of this section. The manifold block has labels stamped near each valve and port location.

The SM must be installed in an area where it is protected from extreme temperature and humidity conditions. Limit conditions are 40° to 125° F and 20 to 80% humidity. A normal shop or laboratory with a non-corrosive atmosphere is recommended.

The SM should be located as close as possible to the actuators it supplies.

Provisions should be made to mount the SM to prevent movements due to hydraulic line transients. The SM may be mounted to steel framework. Ideally, the SM would be mounted in an elevated position to allow for a drip pan during service.

**Appendix A** page 3 illustrates the most common configuration of a Service Manifold connected to one or more Controlled Abort Manifolds. Connections from the Service Manifold to Controlled Abort Manifolds will depend on the test requirements. The **PRS**, **RET**, **MOD** and the **PLT** ports will always need to be connected. The **PRS** and **RET** line sizes will be based on the flow requirements.

The **MOD** and **PLT** lines only carry a static pressure and no or small flow, so they can always be 1/4"

**PARTS BREAKDOWN**

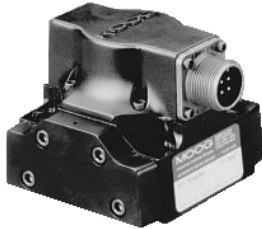
COMPONENT	DESCRIPTION	MANUFACTURER	PART #
V1	Pilot to Open Check Valve	Sun	CKEB-XCN
V2	Direct Acting Pressure Reducing Valve	Sun	PRFB-LAN
V3	Pilot to Close Check Valve	Sun	COFA-XCN
V4	Pilot to Close Check Valve	Sun	COFA-XCN
V5	Pilot to Close Check Valve	Sun	COFA-XCN
V6	Pilot to Close Check Valve	Sun	COFA-XCN
V7	Pressure Compensated Flow Control	Sun	FDEA-LAN
V8	Pressure Compensated Flow Control	Sun	FDEA-LAN
V9	Check Valve	Sun	CXED-XCN
V10	Check Valve	Sun	CXED-XCN
V11	Check Valve	Sun	CXED-XCN
V12	Check Valve	Sun	CXED-XCN
V13	Flow Switch	Sun	LOGCZ-ZDN
V14	Pilot Operated Sequence Valve	Sun	RSDC-LAN
V15	Pilot Operated Sequence Valve	Sun	RSDC-LAN
V16	Pilot to Close Check Valve	Sun	COHA-XAN
V17	Pilot to Close Check Valve	Sun	COHA-XAN
	Servo Valve	Moog	76, 760, G761 Series
	Manifold	Damon	E-28800

**CONTROLLED ABORT MANIFOLD SPECIFICATION SUMMARY**

Pressure Rating	3,000 PSI
Flow	15 GPM per channel 40 GPM per module
Weight	200 lbs.

## 7. Servo Valves

### OVERVIEW



Moog 760 Series

A servo valve is an electrically operated valve that controls how hydraulic fluid is ported to an actuator. In this facility, the actuator is almost always a cylinder. Varying the electrical input signal magnitude can change the flow rate to the actuator and changing the polarity of the input signal can change the direction of flow to the actuator.

The servo valve has either four or five ports. For the 4 port servo valve, one port connects to a fluid supply, one port connects to a reservoir, and two ports connect to each end of a cylinder. The 5 port servo valve is similar to the 4 port except it has an extra port which supplies the spool with a constant fluid stream at all times. This feature is important when the supply pressure is less than 1000 PSI. This allows a separate fluid source at a constant high pressure to act on the spool to improve valve performance.

The majority of the servo valves used in this facility are Moog 76 Series or Moog 760 Series valves. These servo valves are throttle valves for 3-way, and preferably 4-way applications. They are a high performance, two stage design that covers the range of rated flows from .5 to 15 gpm at 1000 psi valve drop. The output stage is a closed center four-way sliding spool. The pilot stage is a symmetrical double nozzle and flapper, driven by a double air gap, dry torque motor. Mechanical feedback of spool position is provided by a cantilever spring. The valve design is simple and rugged for dependable operation.

Servo valves are suitable for electrohydraulic position, speed, pressure, or force control systems with high dynamic response requirements.

### Theory of Operation

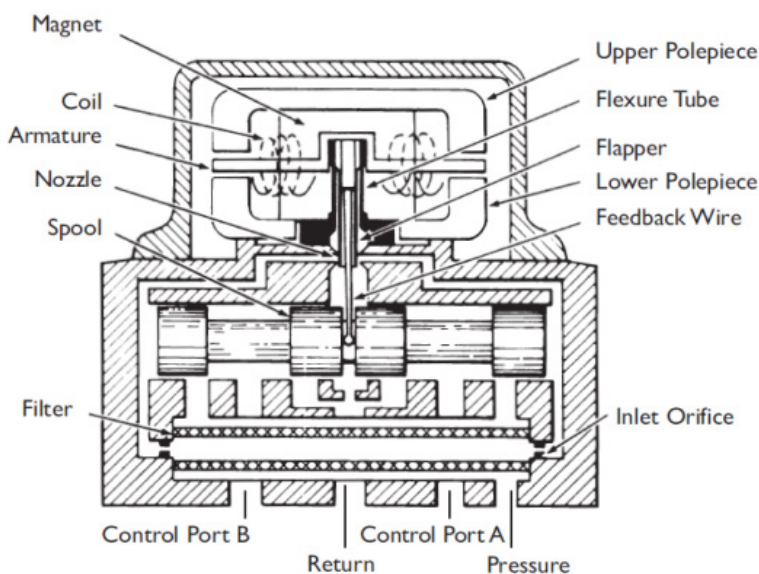
Refer to the figure on the next page for the following discussion. An electrical command signal (flow rate set point) is applied to the torque motor coils and creates a magnetic force which acts on the ends of the pilot stage armature. This causes a deflection of the armature/flapper assembly within the flexure tube. Deflection of the flapper restricts fluid flow through one nozzle which is carried

through to one spool end, displacing the spool.

Movement of the spool opens the supply pressure port (P) to one control port while simultaneously opening the tank port (T) to the other control port. The spool motion also applies a force to the cantilever spring, creating a restoring torque on the armature/flapper assembly.

Once the restoring torque becomes equal to the torque from the magnetic forces, the armature/flapper assembly moves back to the neutral position, and the spool is held open in a state of equilibrium until the command signal changes to a new level.

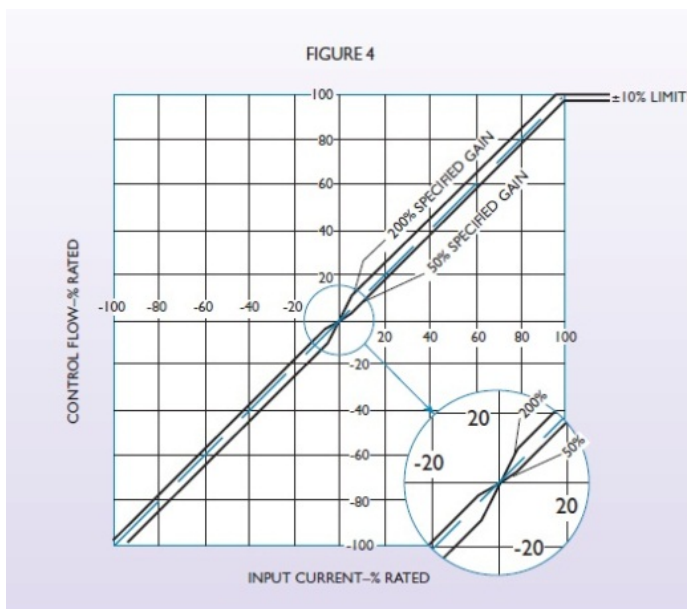
In summary, the spool position is proportional to the input current and, with constant pressure drop across the valve, flow to the load is proportional to the spool position.



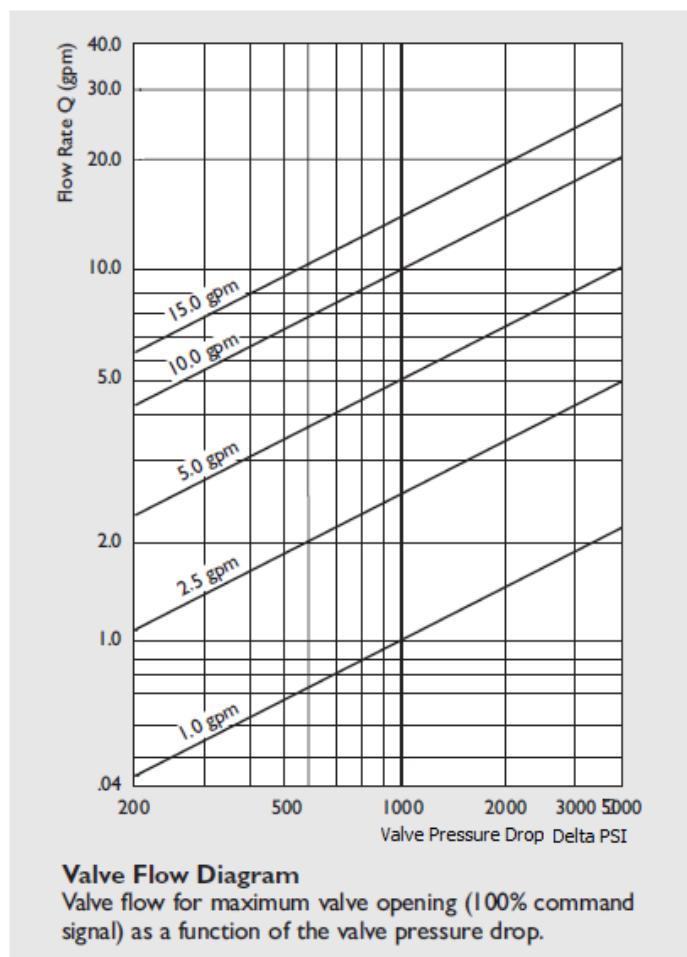
## Technical Data

operating pressure	
ports P, A, B, T	up to 3,000 psi
temperature range	-20 F to 275 F
cleanliness	ISO 4406 < 14/11
vibration	30 g 3 axes

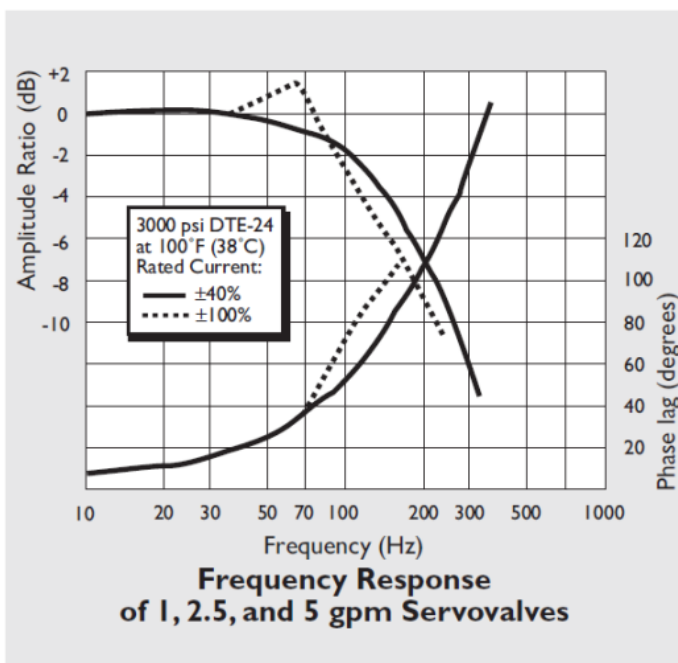
## Rated Flow vs Input Current



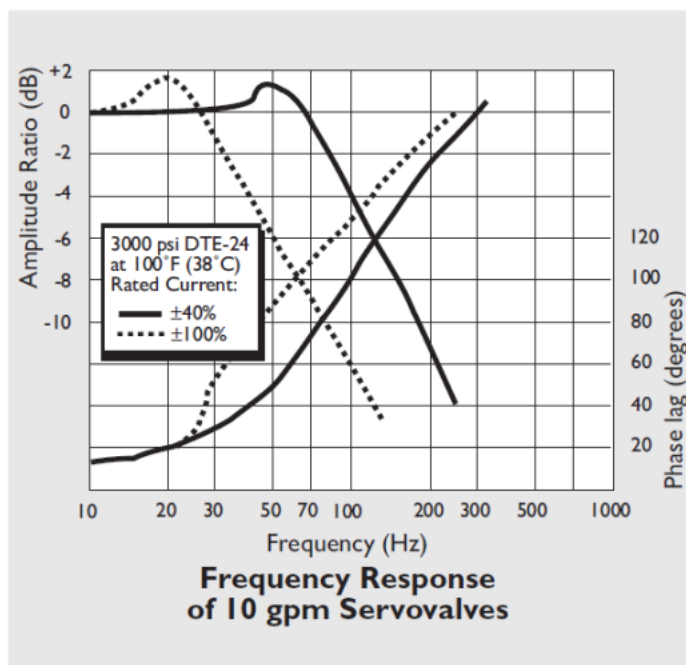
## Flow vs Pressure Drop At Max Command



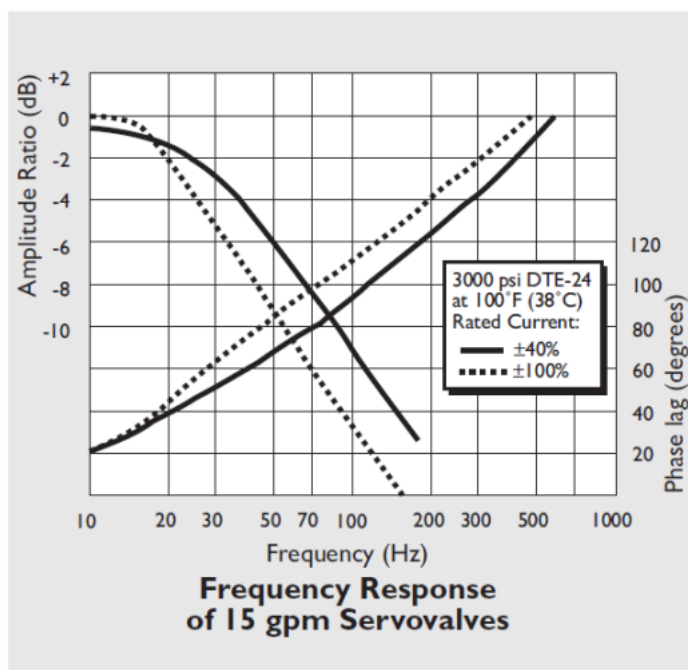
# **Frequency Response For 1, 2.5, and 5 GPM**



# **Frequency Response For 10 GPM**



## Frequency Response For 15 GPM



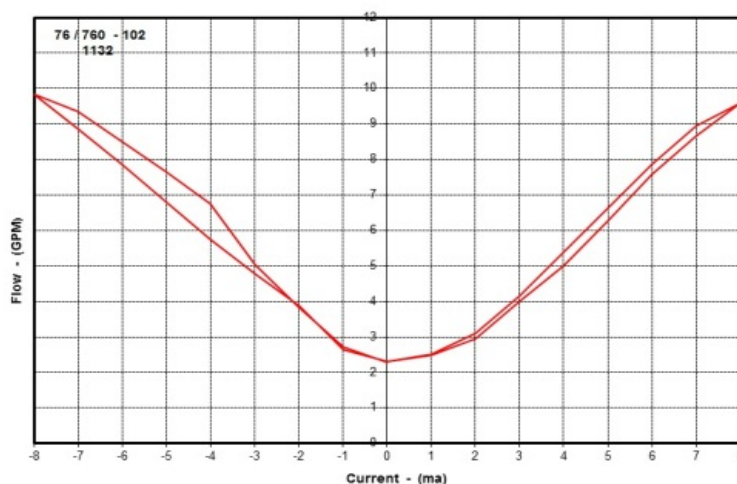
## Flow Checking Servo Valves

Knowing the condition of a servo valve is critical when troubleshooting problems with a control channel. The first step in assessing the condition of a servo valve is to check the flow output throughout the entire input current range. To do this, the servo valve should be put on the test stand to measure its flow independently. Use a manual current input and measure the flow output at discrete current settings. The current should be started at zero, then ramped up to +100%, then back to zero, then ramped up to -100%, and then back to zero again. Data should be taken at intervals of one milliamp. Then plot the data to check for linearity, hysteresis, and internal leakage.

The plot below is an example of a bad servo valve. This valve has a large flow at zero current which indicates the spool is probably worn. The ramps are not linear and the slopes are different. Also there is hysteresis in both directions. This valve needs to be sent out for repair before it is used again.

Sometimes a valve that does not meet factory specifications will still be acceptable. Experience with flow checking many servo valves will give a feel for when a used valve is adequate for a particular application.

Currently there is no method of checking servos for frequency response in this facility. In most cases this is not an issue, since the majority of applications are low frequency or static loading.



## Null Adjustment

The minimum flow rate should occur at zero current input. If this is not true, the valve is out of null. The valve null can be adjusted with the mechanical null adjusting nut. If the valve null is more than .5 milliamp from zero, then it should be adjusted. Set the null while the input current is zero and the supply pressure is at 1000 PSI. Adjust the null adjustment and watch the flow at the same time. When the flow is minimum, lock the null adjustment nut.

## Repairing Servo Valves

Repairing servo valves is best left to the experts. Don't even try to repair a servo valve in-house. Special equipment and tools are required to repair a servo valve back to factory specifications. Be sure to use a reputable repair company to do the work. Require them to use only new replacement parts. Some companies will offer reconditioned parts or recoated spools to reduce costs. It has been general practice to use valves that have been reconditioned to factory specifications on a new hydraulic load system at the beginning of a test.

**Servo Valve Inventory**

MANUFACTURER	MODEL	RATED FLOW (GPM)	QUANTITY
Pegasus	142M	0.5	20
Moog	76-100	1	3
Moog	760-100A	1	17
Moog	76-101	2.5	10
Moog	73-101	2.5	10
Moog	76-102	5	5
Moog	760-102A	5	15
Moog	76-103	10	2
Moog	760-103A	10	8
Moog	76-104	15	10

## 8. Emergency Dump Buttons

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### OVERVIEW

Emergency dump buttons are a critical part of any hydraulic system. They provide a means of turning off machines and shutting off oil flow in emergency situations. Before starting any hydraulic system or machine, you should know how to stop it in an emergency. For example, a hydraulic line may burst and start spraying fluid all around. Obviously, the supply to this hose needs to be shut off. But what is the best way to shut off the supply to this hose? How can this particular hose be shut down and affect the least amount of other users of the facility hydraulic system? There are different types of dump buttons that control a hierarchy of flow paths.

### Pump Dump Buttons

Some dump buttons are used to shut down a pump which supplies oil to the entire facility's distribution lines. In this case, when the button is pushed everything in the facility using hydraulics will lose pressure. An example of when this should be used is if there is leak in the pump room or one of the main distribution lines throughout the facility is leaking. These buttons should be the last resort to shutting down an emergency situation.



### Branch Circuit Dump Buttons

Other dump buttons shut down a particular circuit which branches from the main hydraulic distribution lines. A test site would be an example of a branch circuit. The FIRST Lab (when using the main supply) is another example of a branch circuit. In this case, there could be a number of reasons that the flow needs to be shut off. For example, there may be a hose leak. Or maybe a test article is causing an unsafe situation. For whatever reason, a particular test site could be stopped without affecting any other branch circuit. Almost all branch circuits will begin with a hand valve and a Service Manifold which can shut off the flow to that branch. The use of this dump button is preferred over the Pump Dump Button when possible.



Test Site Dump Button



FIRST Lab Dump Buttons

### Equipment Dump Buttons

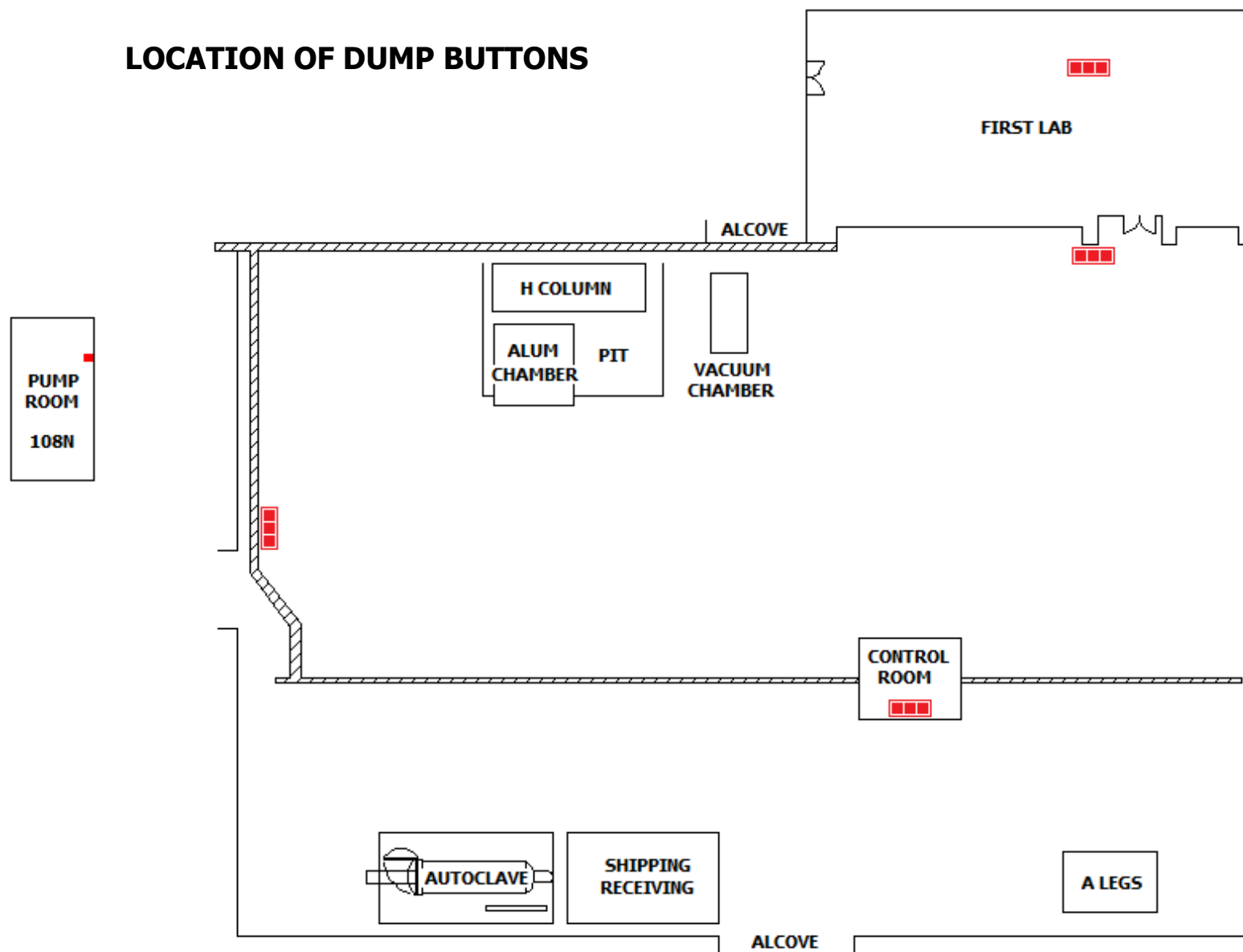
Some dump buttons only shut down a particular piece of equipment which could be supplied by either the main hydraulic lines or from a branch circuit.



### **Dump Button Locations**

Most Pump Dump Buttons locations are fixed, but may change over time. The current locations of Pump Dump Buttons are shown in red in the figure on the next page. Branch Circuit Dump Buttons will be constantly changing depending on current test cell configurations, with the exception of the FIRST Lab. Therefore, some type of periodic training of locations should be practiced and button labeling should be updated to reflect the current use of each button.

## LOCATION OF DUMP BUTTONS



## 9. Oil Care Program

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### Program Objective

The objective of the oil care program is to maintain very clean oil to maximize and extend the life of the components used to make up the Building 65 hydraulic system. This program uses a Parker Par-Test® analysis which provides a spectrometric analysis, particle counts, viscosity, and water content of the oil. The oil particulate contamination level will be maintained at an ISO 4406 rating of 16/13/9 to meet the cleanliness requirements recommended for high – performance servo hydraulic equipment which includes servo valves.

This oil care program will treat the two hydraulic systems as separate entities. They will be known as System #1 and System#2.

A crucial requirement of this program is to be consistent in taking samples from the same sampling sites each time, following the same procedure to extract the oil samples each time, and always using the same laboratory to perform the analysis. Any variation from the program plan described here will yield data that will be less useful.

### Sampling Locations

There are 11 locations throughout the hydraulic system that have been designated as sampling sites for oil to be extracted for analysis. These locations are shown on the Boost Pump Skid schematics and High Pressure Pump schematics in **Section 3**. They are as follows:

#### **SYSTEM #1**

Reservoir #1  
Boost Pump Filter Inlet #1  
Boost Pump Filter Inlet#2  
HP Pump #3  
HP Pump #4

#### **SYSTEM #2**

Reservoir #2  
Boost Pump Filter Inlet #3  
Boost Pump Filter Inlet #4  
HP Pump #7  
HP Pump #8

FIRST Lab Main Return Line

### **Sampling Procedure**

Obtaining a fluid sample for particle counts and/or analysis involves important steps to make sure you are getting a representative sample. Often erroneous sampling procedures will disguise the true nature of system cleanliness levels. Use the following procedure to obtain a representative system sample.

1. Operate the system for at least ½ hour.
2. Remove the valve cap at sample location.
3. With the system operating, open the sample valve and allow 7 to 16 ounces of fluid to flush the sampling port.
4. Place a pre-cleaned sampling bottle in the stream of flow from the sampling valve. Fill the bottle to 1 inch from the top.
5. Close the sampling bottle immediately. Next close the sampling valve. Be sure to make provisions for catching the fluid while removing the bottle from the stream.
6. Label the bottle with the pertinent data: sampling port location, fluid supplier and code (Mobil DTE 24), date.
7. Replace the valve cap.

### **Sampling Schedule**

Oil sampling will be an integral part of the Building 65 PM/PMI program. The Par-Test® analysis will be performed every six months to monitor particle counts, viscosity, and water content of the oil.

### **Oil History and Trends**

All of the reports received from the analysis shall be kept in a folder and used for trending purposes. A history of the oil health can be used to determine when the oil has reached its useful life and aid in troubleshooting system component wear.

**Reading a Fluid  
Analysis Report**

A sample Fluid Analysis Report is shown on page 65. A lot of information about the oil condition can be found here. At the top of the page you will see the overall condition of the machine located near the sample location and also you will see the condition of the oil sampled at this location.

Below that, you will see information about the oil, the machine, sample date, etc. Next is a list of problems and customer notes.

In the middle of the page is a Spectroscopic Analysis (SA) which shows particle counts of different elements found in the oil. This distribution can be used to determine component wear. Possible sources of elements in the oil are listed in the following pages.

The graphs to the right of the SA show a history of some oil characteristics over time. This information can be used to decide when the oil has reached the end of its useful life.

Other information such as water content, acid content, oxidation, and other can be found in the report as well.

**ISO Cleanliness  
Code**

The ISO Code is a critical set of numbers which quantify particulate contamination levels per milliliter of fluid at three sizes: 4 $\mu$ , 6 $\mu$ , and 14 $\mu$ . This ISO code is expressed in 3 numbers: 19/17/14. Each number represents a contaminate level code for the correlating particle size. The code includes all particles of the specified size and larger. It is important to note that each time a code increases the quantity range of particles doubles. Table 1 below gives the Range Codes and Particle Sizes.

The target ISO code for a system is based on the most sensitive component in the system. Each component will have a recommended ISO code established by the manufacturer. In this facility the most sensitive components are typically servo valves. Servo valves require an ISO code of 16/13/9.

**ISO 4406:1999 Code Chart**

Range Code	Particles per milliliter	
	More than	Up to / Including
24	80000	160000
23	40000	80000
22	20000	40000
21	10000	20000
20	5000	10000
19	2500	5000
18	1300	2500
17	640	1300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5
7	0.64	1.3
6	0.32	0.64

**Table 1 ISO Codes**



Tel: 216-251-2510, Fax: 216-251-2515

Machine Condition: **NORMAL**  
 Lubricant Condition: **MARGINAL**  
 Facility Hydraulic Pump -2A

V3572-2

## Analysis Report

Lube Type: MOBIL DTE 24  
 Machine MFG: VICKERS  
 Machine MOD: PVXS-180-M-R-DF-0260-000-2A  
 MachineType: Industrial Pump

Received: 11/23/2010 2:21:00PM  
 Report: 11/23/2010 6:48:00PM  
 Sample No: 1749 - 65 - 1 - 4  
 Analyst: MMM

ATTN: Charlie Thomas  
 DOD USAF AFRL  
 2790 D Street, Bldg. 65, Area B  
 Wright-Patterson AFB, OH 45433

## Problems:

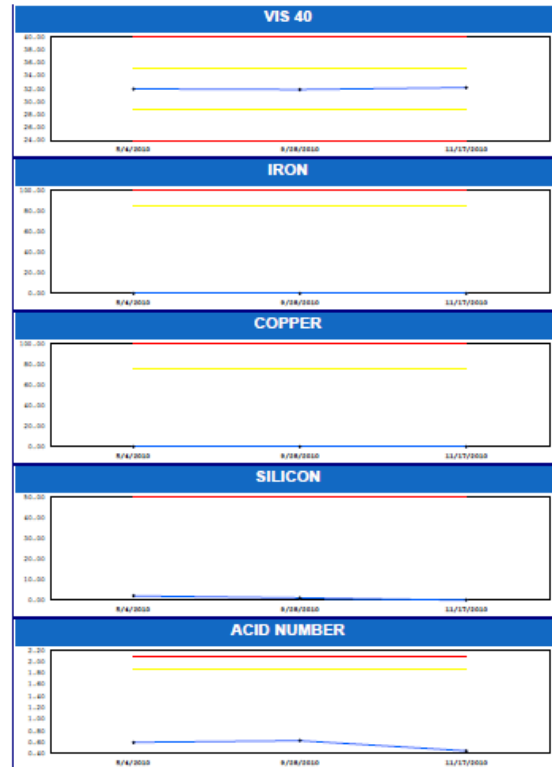
\*\*\* EXCESSIVE PARTICLE COUNT.

## Customer Notes:

Last oil change on 6/15/2009 Facility sample technique #8

The particulate contamination exceeds our limits for a industrial pump (16/13/9). High particulate contamination will lead to abrasive wear and damage internal components. Reducing particle levels will significantly extend component life.

Lab No	Reference	11/17/2010	9/28/2010	5/4/2010	5/4/2010
363099	662826	648343	603764	603763	
Oil Chng / Mach / Lube		N / N / M	N / N / M	N / N / M	Y / N / M
<b>SPECTROSCOPIC ANALYSIS (ppm) ASTM D 5185</b>					
Iron	0	0	0	0	1
Copper	0	0	0	0	0
Lead	0	0	0	0	0
Aluminum	0	0	0	0	0
Tin	0	0	1	1	0
Nickel	0	0	0	0	0
Chromium	0	0	0	0	0
Titanium	0	0	0	0	0
Vanadium	0	0	0	0	0
Silver	0	0	0	0	0
Silicon	0	0	1	2	5
Boron	0	0	0	0	0
Calcium	199	97	95	87	86
Magnesium	1	0	0	0	0
Phosphorus	540	393	374	412	420
Zinc	761	478	456	502	487
Barium	0	15	14	16	16
Molybdenum	0	0	0	0	0
Sodium	1	2	2	2	2
Potassium	0	3	3	1	2
<b>VISCOSITY (centistokes) ASTM D 445</b>					
Vis 40	32.9	32.1	31.8	31.9	31.8
<b>FTIR SPECTROSCOPY (indexing numbers) JOAP Method</b>					
Anti Wear	13	10	11	10	11
Nitration	3	2	2	2	2
Other Fluid	29	41	43	39	40
Oxidation	2	0	1	2	5
<b>PARTICLE COUNT (particles per ml) ISO 4406:99</b>					
ISO Code	18/ 17/ 13	15/ 14/ 10	18/ 17/ 13	18/ 17/ 13	18/ 16/ 12
>4 Micron	2205	234	1785	1681	1343
>6 Micron	857	91	694	653	522
>14 Micron	65	6	52	49	39
>50 Micron	2	0	2	2	1
>100 Micron	0	0	0	0	0
<b>SINGLE COMPONENT TESTS</b>					
Acid # mg KOH/g		0.44	0.62	0.59	0.53
Water %		NEG	NEG	NEG	NEG



DOD USAF AFRL assumes sole responsibility for the application of and reliance upon results and recommendations reported by Insight Services, whose obligation is limited to good faith performance.

**Possible Sources of  
Elements in Oil**

1. Aluminum (Al) --Pistons, bearings, bushings, pump vanes, blower / turbos, washers, dirt, shims
2. Antimony (Sb) -- Babbit bearings, greases
3. Barium (Ba) -- New oils (dispersant/detergent), grease, water
4. Boron (B) --New oils, coolant, seals, dust, fuel dilution
5. Cadmium (Cd) -- Bearings, platings
6. Calcium (Ca) -- New oils (dispersant/detergent), water, grease
7. Chromium (Cr) -- Plated parts (primarily piston rings), coolant, anti-friction bearings, shafts, gears, seals, bearing cages, fuel leaks gas turbines.
8. Cobalt (Co.) -- Bearings, turbine components
9. Copper (Cu) -- Bearings, bearing cushions, bushings, thrust washers, valves, guides, injector shields, oil cooler tubes, wet clutches, coolant (copper radiator), gears
10. Iron (Fe) -- Rings, crankshaft, cylinder walls, valve train, pistons, anti-friction bearings, gear train, shafts, clutch plates, washers, rust, water
11. Lead (Pb) -- Babbit or copper-lead bearings, platings, leaded gear lubes, leaded gasoline, grease, paint, seals, solder
12. Magnesium (Mg) -- New oils (dispersant/detergent), bearings, superchargers, water
13. Manganese (Mn) -- Steels, shafts, valves, corrosion, blowers (exhaust & intake systems)
14. Molybdenum (Mo) -- Additives, piston rings, electric motors

15. Nickel (Ni) -- Shafts, valves, anti-friction bearings, gears, rings, turbine components

16. Phosphorous (P) -- New oils (zinc dithiophosphate), chlorinated phosphorous anti-wear additives, gears, coolant leaks

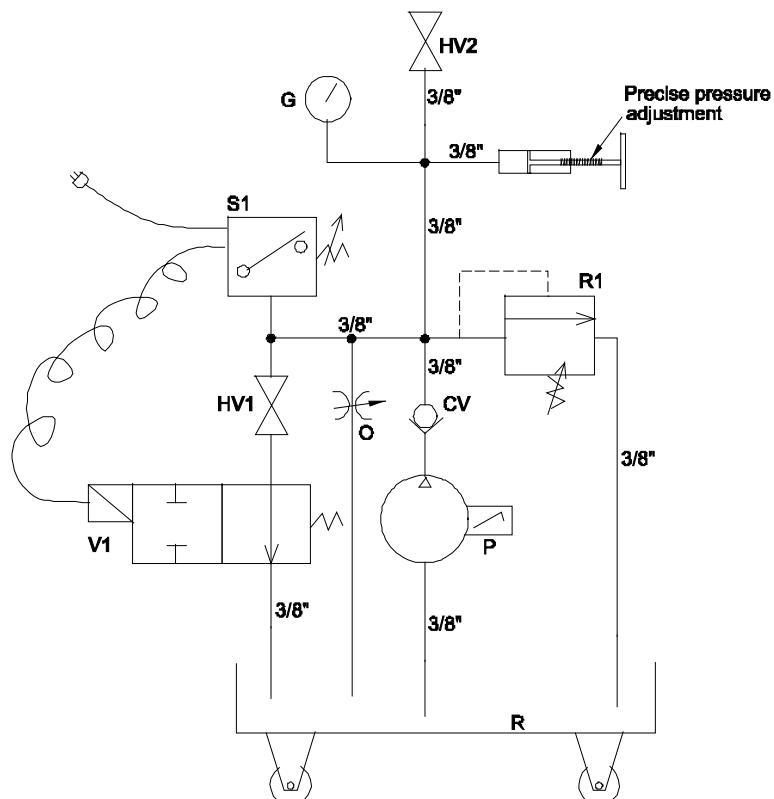
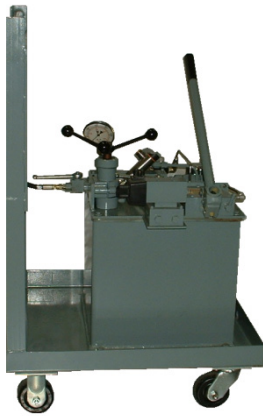
## 10. Other Essential Equipment

Not all load testing requires the use of a sophisticated load control system. Sometimes it is necessary to apply a single static load or a simple slow load profile. Sometimes you don't have time to setup and program a control system. There are other devices available to perform these types of tests. They allow tests to be performed much faster and still offer an acceptable level of safety.

### Hand Pump

A hand pump can be used to perform a variety of simple load tests. The hand pump can output a single pressure that could be connected to one or multiple actuators. It can be used to apply a static load or a simple slow load profile.

It is a portable self-contained package that contains a fluid reservoir, a pump, an overload protection system, and a dump function. A schematic of the system is shown below.



The hand pump **P** is manually operated by pulling a lever to adjust an output pressure and therefore a load on an actuator. The output pressure can be increased in discrete increments with the lever operated pump to an approximate pressure value. Then an inline infinitely variable piston can be adjusted to achieve a more precise pressure value. The operator can read an onboard pressure gauge for rough order load magnitudes. Or the operator could use some type of external display to show precise load values during operation.

A pressure relief valve **R1** can be set to prevent the operator from exceeding a maximum pressure value. In addition, a pressure switch **S1** in combination with a solenoid valve **V1** can be used to provide a dump function to prevent over loading. The dump function can be disabled by closing valve **HV1**. A variable orifice **O** can be used to ramp the pressure down.

### Edison Load Maintainer



Another device, the Edison Load Maintainer (ELM), can be used to manually apply up to ten different static loads simultaneously or ten simple slow load profiles simultaneously. Before using the ELM, consult the manufacturer's Users Guide to gain a thorough understanding of its operation. This discussion is just a high level overview of how it works.

The Edison Load Maintainer is basically a system of ten independent pressure regulators that can have their setting adjusted simultaneously by the operator. The unique thing about the ELM is that each channel (or regulator) can have a different maximum pressure setting and all of the channels can be adjusted from 0 to 100% of their maximum value at the same time. In fact, it is necessary that all channels be at the same percent of maximum set output pressure at all times.

The ELM requires an external fluid supply and has a maximum flow rate of 1 GPM for each channel. The ELM also requires a 110 VAC source that cycles the channels.

The ELM has a dump function which dumps all the channels simultaneously. A dump can be achieved manually by pushing a bar on the front of the cabinet or it can be dumped by energizing a solenoid which pulls the bar.

### Hydraulic Test Stand



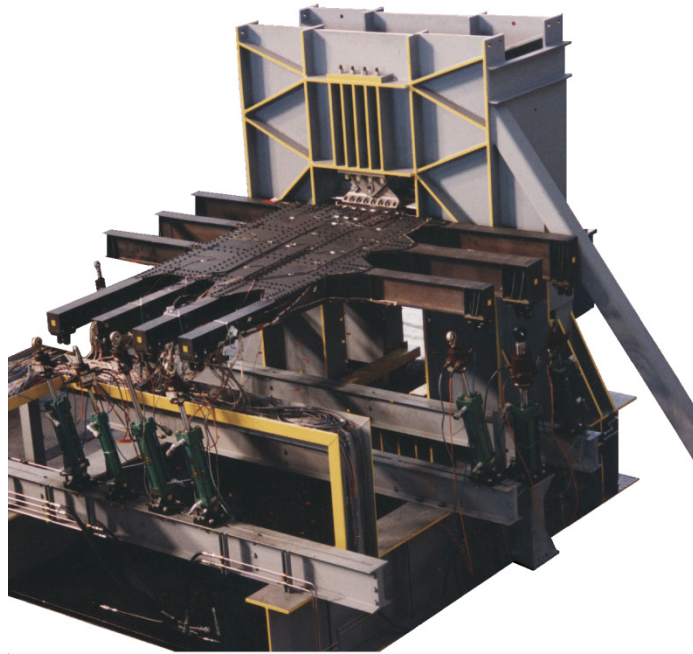
Another valuable tool that has many uses is the Hydraulic Test Stand. It can be used for component checkout, circuit development, calibrations, and numerous other things. Before using the Test Stand consult the manufacturer's Users Guide to gain a thorough understanding of its operation. This discussion is just a high level overview of capabilities and uses.

The test stand is a self-contained system which has a fluid reservoir, a boost pump, a high pressure pump, and several ports for connecting external devices. The test stand is designed to allow the user to easily set pump output pressures, set back pressures, read flow rates, provide fluid directional controls.

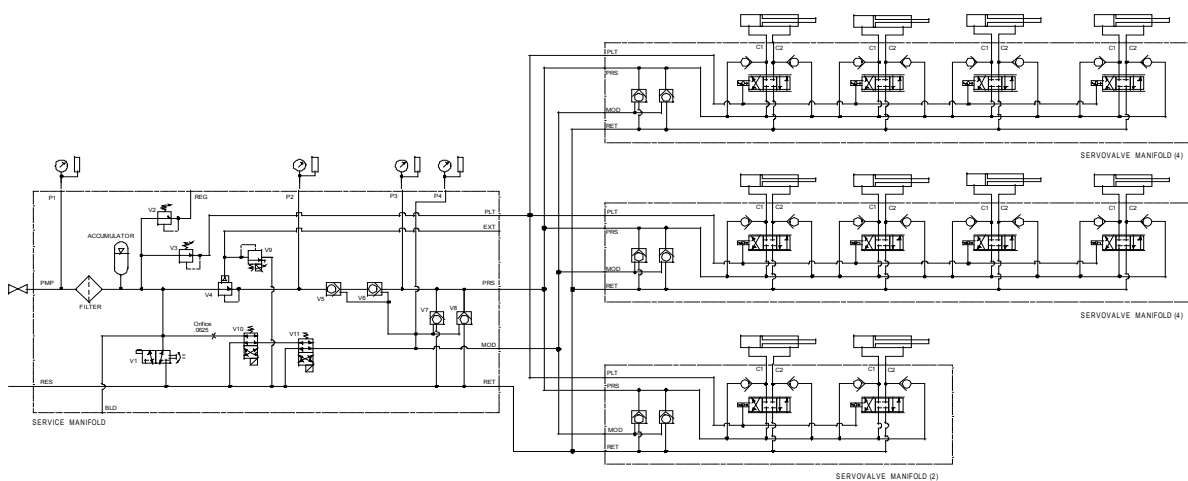
The Test Stand is ideal for performing servo valve flow rate checks. It has several quick disconnects to allow for circuit design and checkout.

## 11. Historical Circuits and Applications

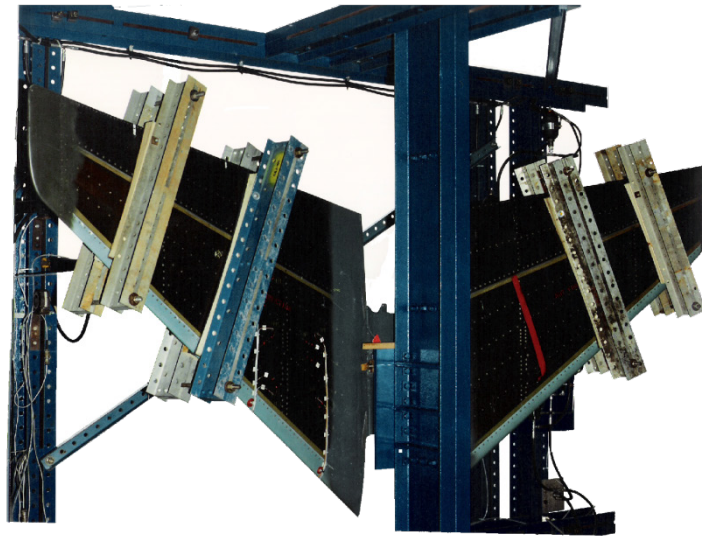
### TMC Wing Box Test



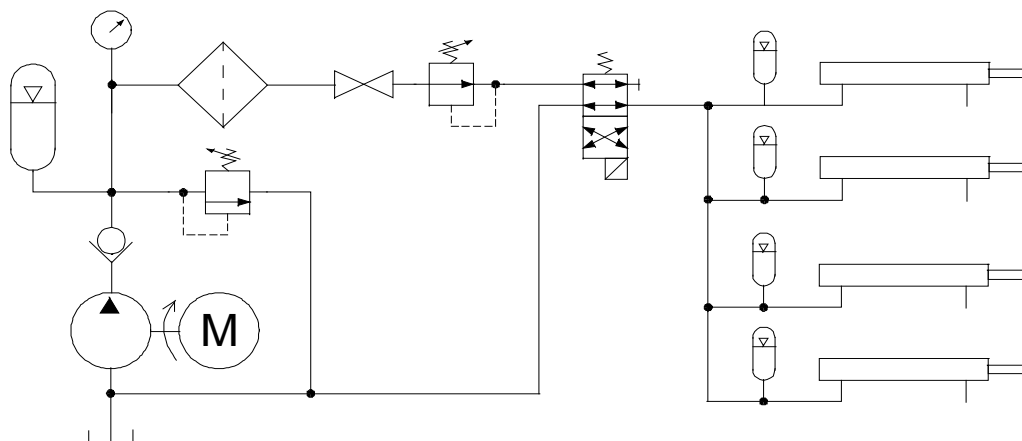
The TMC Wing Box test had ten closed loop load control channels. The circuit used a Service Manifold, 3 Servo Valve Manifolds, 10 servo valves, and 10 cylinders. The circuit for this test is shown below.



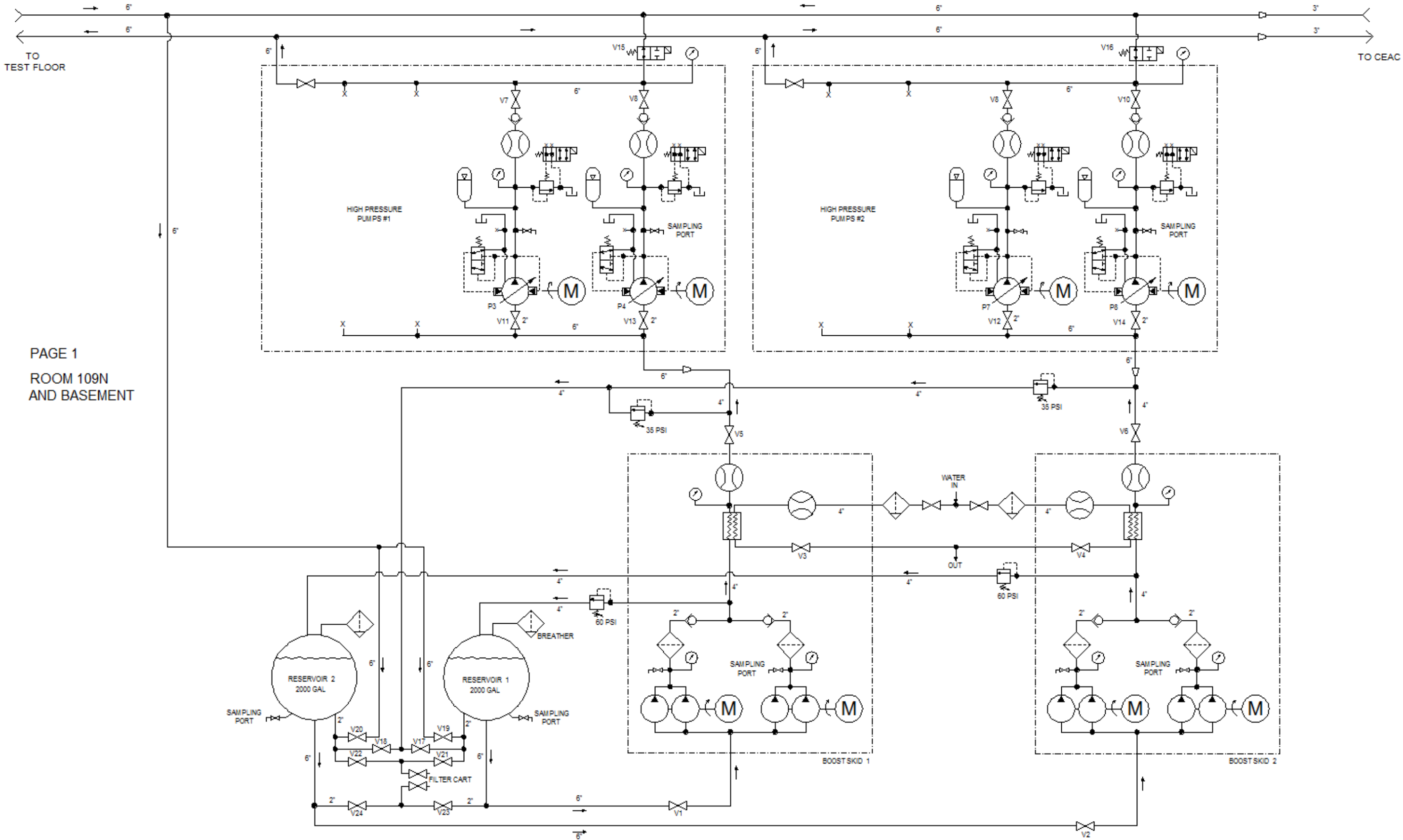
## AV-8 Horizontal Stabilator



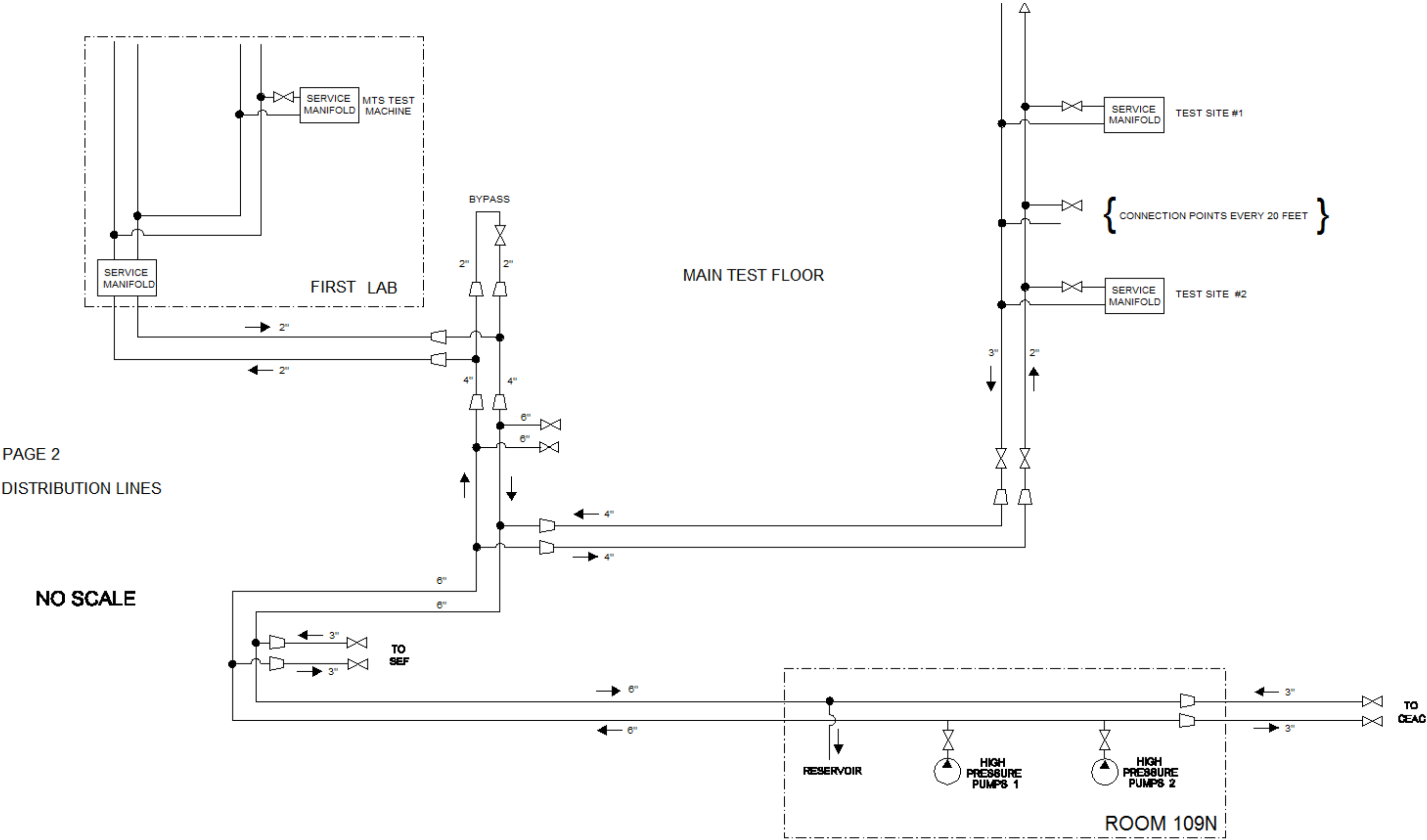
The AV-8 Horizontal Stabilator test had four static loads applied. The loads were open loop. The Stabilator was loaded symmetrically with two equal loads on each side. All the cylinders were the same size. There was one load for the inboard location and one load for the outboard location. The loads were set by setting a pressure regulator to achieve the correct load value. Each cylinder had an accumulator to maintain a load if failure occurred and a large displacement resulted. A solenoid valve performed the dump function. The circuit for this test is shown below.



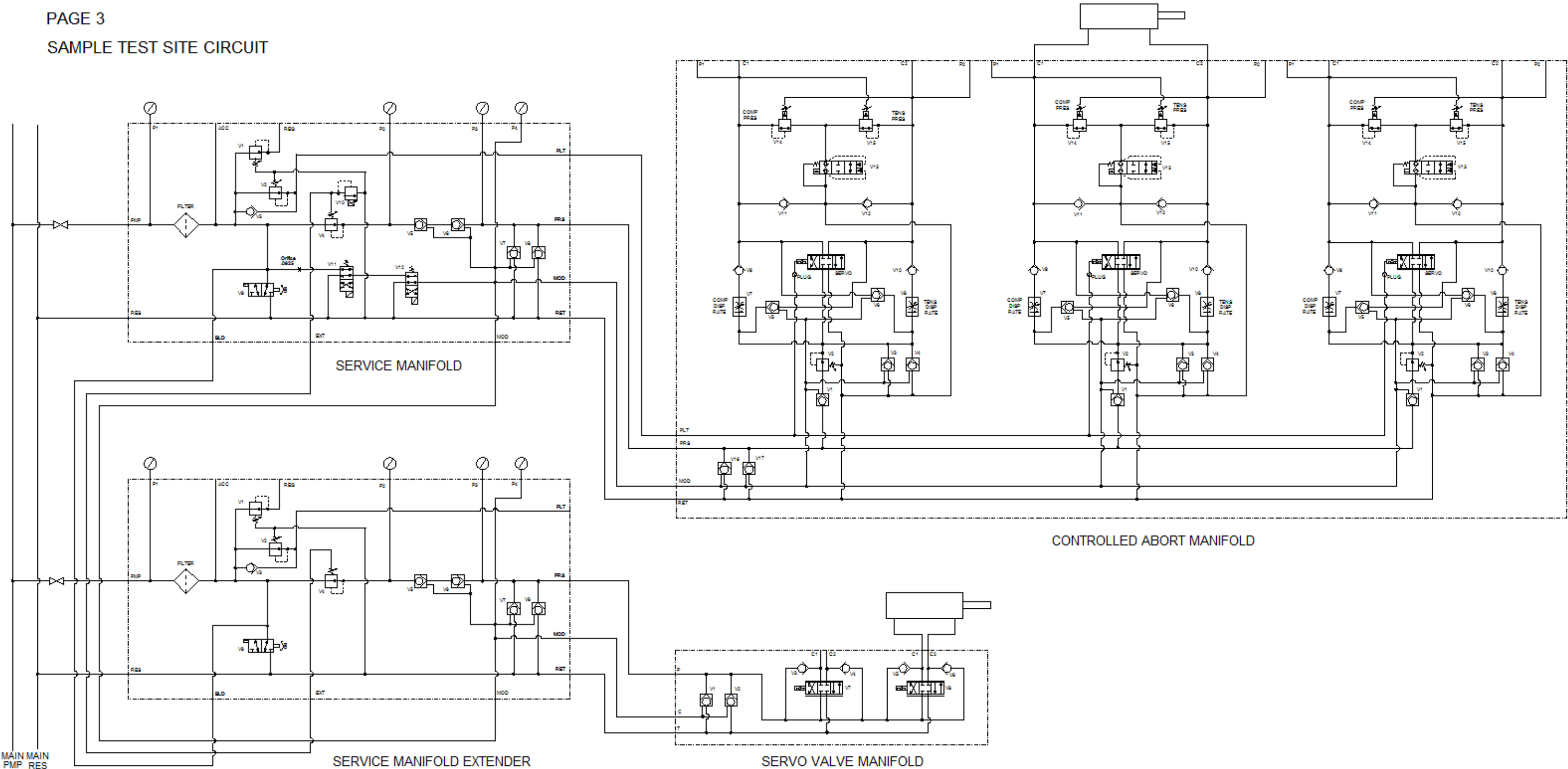
APPENDIX A Facility Hydraulic System Schematics



PAGE 1  
ROOM 109N  
AND BASEMENT

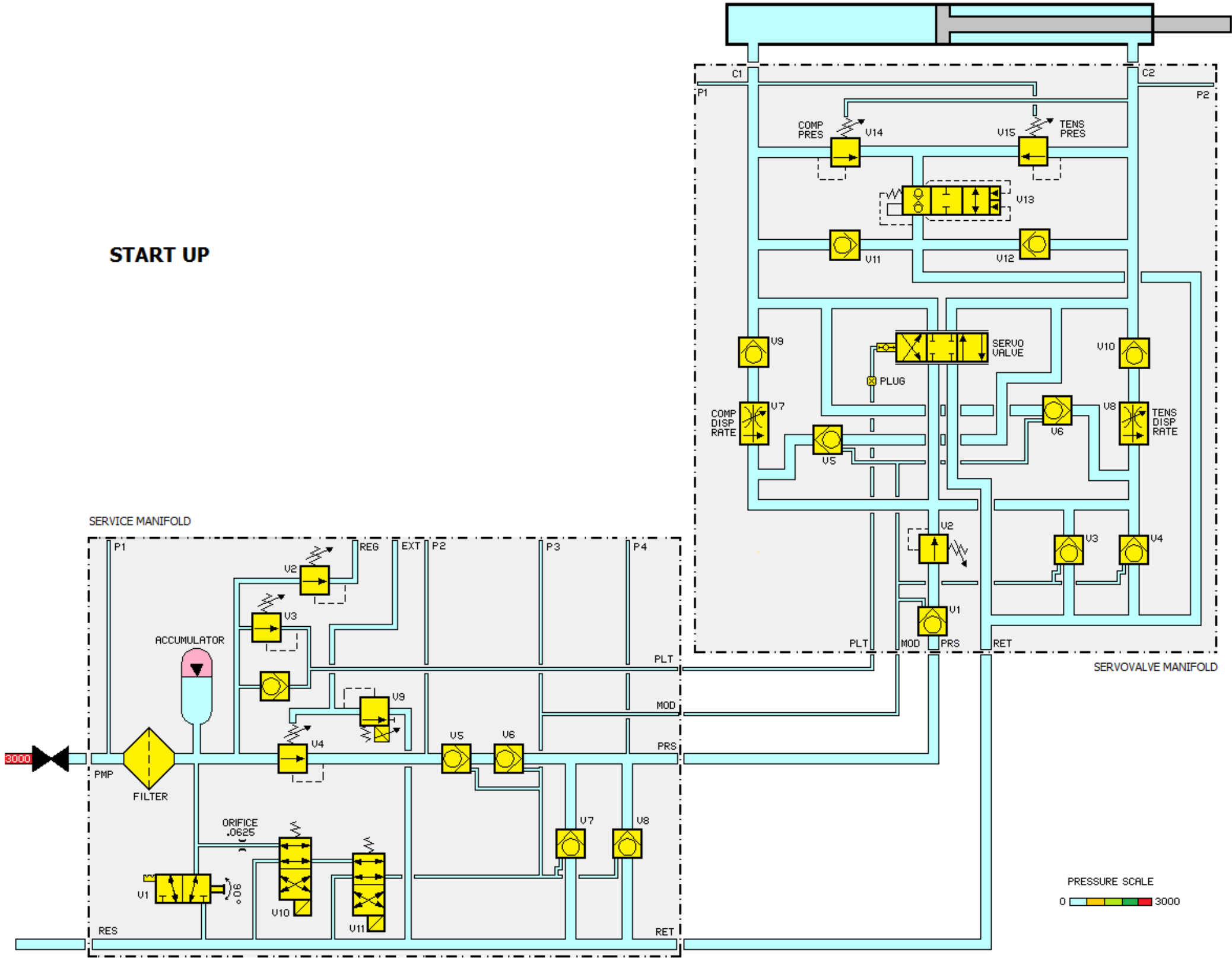


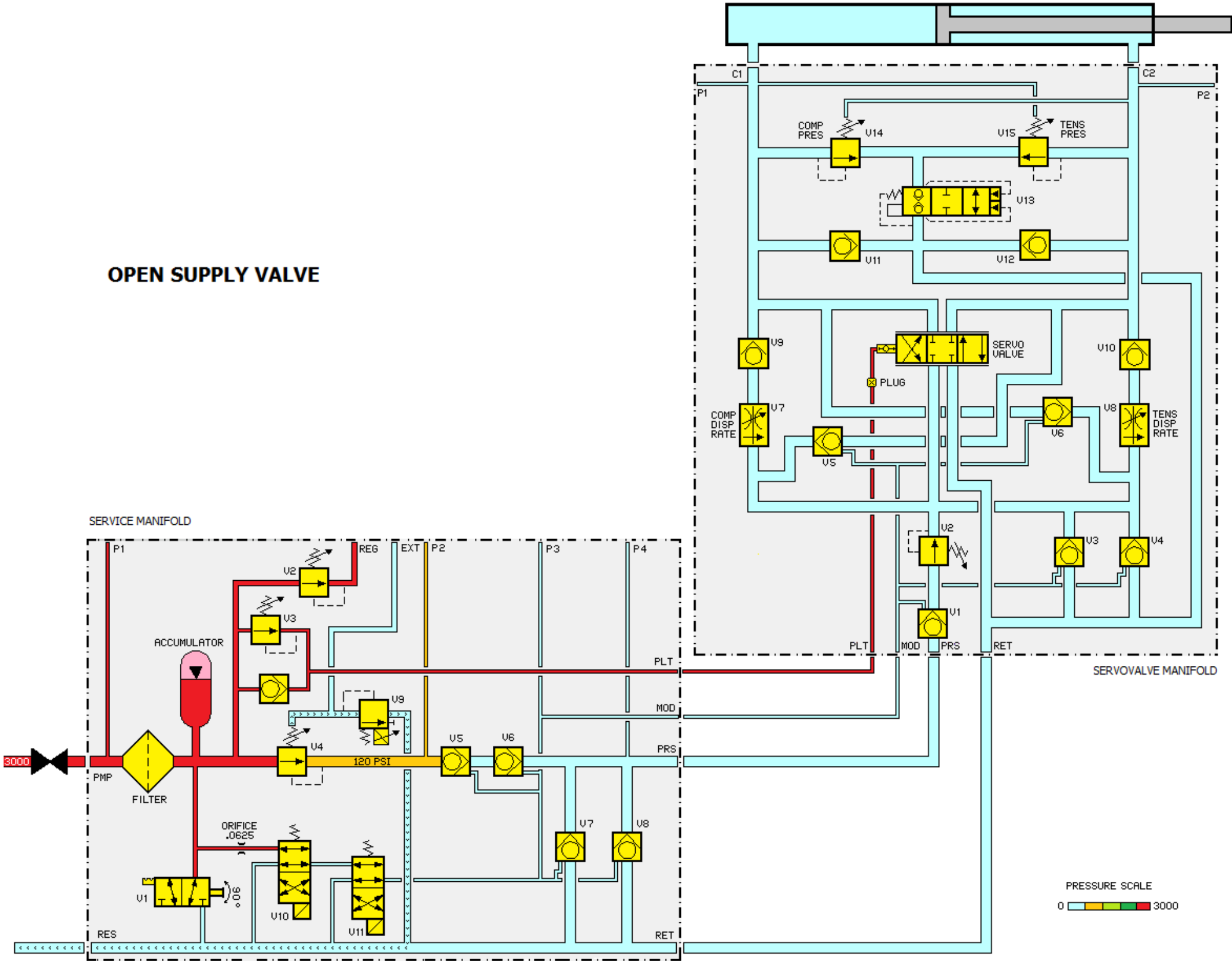
PAGE 3  
SAMPLE TEST SITE CIRCUIT

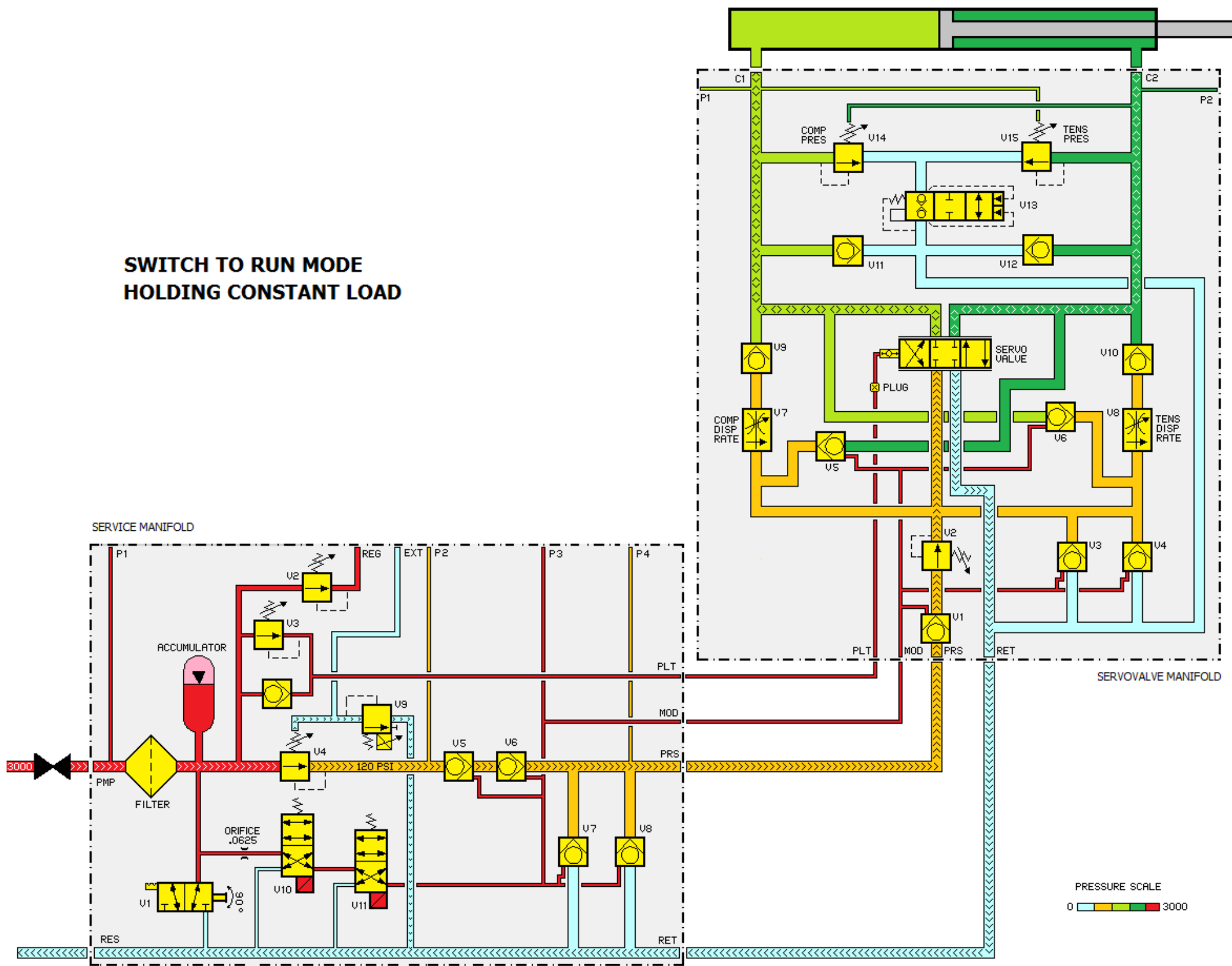


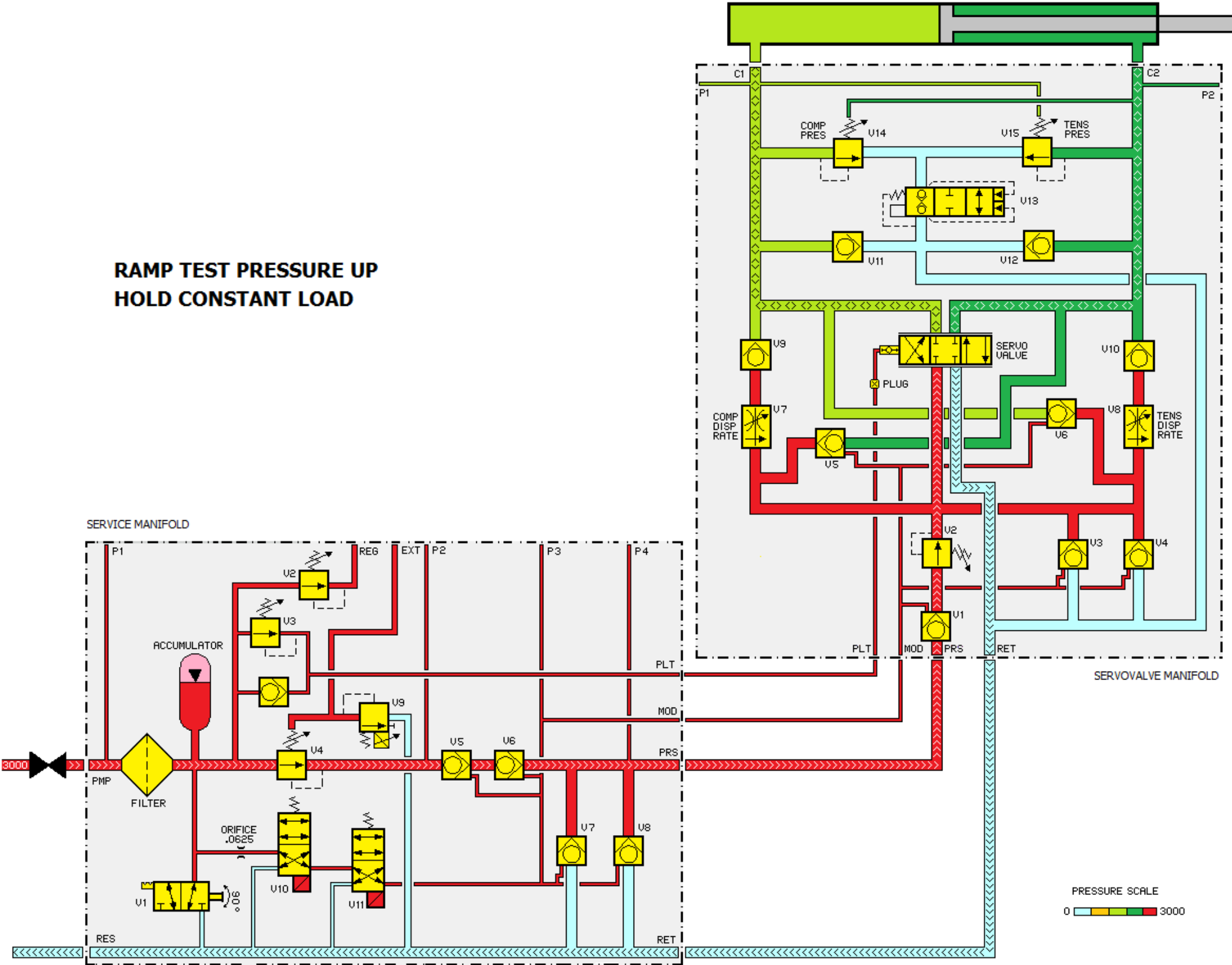


APPENDIX C Service Manifold and Controlled Abort Manifold Operation Diagrams









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